Innovation for Sustainable Aviation in a Global Environment

Proceedings of the Sixth European Aeronautics Days

Madrid, 30th March to 1st April 2011

Edited by
Dietrich Knörzer
Joachim Szodruch

IOS Press

INNOVATION FOR SUSTAINABLE AVIATION
IN A GLOBAL ENVIRONMENT

This page intentionally left blank

Innovation for Sustainable Aviation in a Global Environment

Proceedings of the Sixth European Aeronautics Days

Madrid, 30 March – 1 April 2011

Edited by

Dietrich Knörzer

and

Joachim Szodruch

IOS Press

Amsterdam • Berlin • Tokyo • Washington, DC

ISBN 978-1-61499-062-8 (print)
ISBN 978-1-61499-063-5 (online)
Library of Congress Control Number: 2012943288

European Union:
ISBN 978-92-79-22968-8
Catalogue number KI-31-12-481-EN-C
doi:10.2777/69176

Publisher
IOS Press BV
Nieuwe Hemweg 6B
1013 BG Amsterdam
Netherlands
fax: +31 20 687 0019
e-mail: order@iospress.nl

Distributor in the USA and Canada
IOS Press, Inc.
4502 Rachael Manor Drive
Fairfax, VA 22032
USA
fax: +1 703 323 3668
e-mail: iosbooks@iospress.com

PRINTED IN THE NETHERLANDS

Preface

The Sixth European Aeronautics Days 2011, organised by the Spanish research agency CDTI and supported by the European Commission, took place in the Madrid Palacio Municipal de Congresos from 30th March to 1st April 2011. It was the largest Aerodays conference so far with more than 1400 participants coming from 45 countries, with an extensive exhibition area and numerous side-events of strategic importance to Europe's aeronautical research and innovation.

The Aerodays offered a great opportunity for aviation stakeholders at all levels to meet and discuss the latest advances in aeronautics and air transport, not only in Europe but also worldwide. Representatives from industry, research centres, universities and politics highly appreciated the opportunity to receive top-level information on strategies as well as on the advances of specific research programmes. The unique chance to meet and communicate across all branches and hierarchies opened up new partnerships and encouraged potential future collaboration.

Furthermore, the Aerodays offered the perfect scenario and timing to present Europe's Vision for Aviation, '*Flightpath 2050*'.

Innovation for Sustainable Aviation in a Global Environment

The conference motto is clearly directed towards the future challenges of aviation as well as to the recent political strategies of the European Commission. The general messages from the Commission and high level industrial and research leaders provided a clear view on the way ahead in research and innovation. It also highlighted the importance of aeronautical research within the Framework Programme.

Preparing the Future of Aviation

On the basis of global development it is evident that only in a joint European effort can the future in aeronautics be mastered. Industrial needs and environmental goals require research and innovation efforts leading eventually to an economically viable and environmentally sustainable air transport where aircraft, airports, air traffic management and operation contribute to a balanced and overall optimised system.

Aviation Technologies

Excellent overviews and insights into various community research projects were provided. The very good progress in *greening of the air transport* with topics in flight physics-, noise and vibration-, propulsion- and climate research as well as solutions for alternative fuels were presented. Equally important contributors to future aviation goals are *air traffic operations* and certainly *cost efficiency*, including structures-, systems-, production- and maintenance technologies.

Within the section *pioneering the air transport* a high emphasis was placed on the longer-term view into the future of aeronautics and the innovative solutions with a high potential for fulfilling the goals of Europe's ambitious vision.

The *safety* and *security* sessions provided an insight into the overall mandatory certification aspects of novel technologies and presented important developments in securing the air transport system of the future.

National and International Programmes

The excellent results in Europe for building the future of aviation are not only based on programmes of the European Commission but are a common achievement together with the specific research programmes of the Member States. European institutions and national research establishments have also aligned their goals to the European vision. Complimentary research and the advances in forming sustainable European networks supported by initiatives of the European Commission have resulted in outstanding achievements and an engaged and powerful workforce in industry, research and academia.

However, aeronautics is part of a global community and dependent on worldwide developments. Thus international cooperation is mandatory and strongly supported.

Europe's Vision 'Flightpath 2050'

Europe's Vision for Aviation '*Flightpath 2050*', setting out a European vision for the future of aviation, emphasises where those working in aviation see the priorities for the relevant policy, research and innovation instruments. It is a high-level vision of Europe leading with an aviation industry that is clean, competitive, safe and secure. At the Aerodays perspectives were shown how to implement this new Vision 2050 through a way forward to the new Strategic Research and Innovation Agenda (SRIA).

Post-Conference Proceedings

After almost ten years of European research within the 6th and 7th Research Framework Programmes (2002–2006; 2007–2013) and in view of the coming Framework Programme '*Horizon 2020*' (2014–2020) the Commission decided to support the publication of this special issue of the Conference Proceedings of the Aerodays in Madrid. Assisted by the Scientific Advisory Committee, selected papers from the policy and technical sessions were collected with the intention to provide the reader with a representative picture of the main themes and issues addressed.

The proceedings are divided into three main chapters:

- Policy and Strategy
- Aviation Technologies and Operations
- National and International Programmes

Due to the strategic importance of this conference the proceedings constitute a reference document providing an overview on aeronautical research within Europe especially devoted to Commission supported programmes and networks.

Scientific Advisory Committee

A Scientific Advisory Committee was set up by the European Commission in order to provide advice on the scientific and technical content of the Aerodays Conference as well as evaluate and coordinate the final content of these proceedings. Its members were:

Fred Abbink
Luis da Costa Campos
Anders Gustafsson
Jim Lawler
José Martin Hernandez
Fernando Monge Gómez
Cesar Puentes
Christian Pusch
Dieter Schmitt
Clyde Warsop

Acknowledgements

We wish to acknowledge our gratitude and thanks to the members of the Scientific Advisory Committee and to the authors of the papers for their great effort and cooperation to realise these Post-Conference Proceedings. We would also like to thank sincerely Jean-Pierre Sanfourche of the Council of European Aerospace Societies (CEAS), who acted as the co-ordinating editor for the whole book, and Ms Krisztina Simonne-Paldy of the Aeronautics team of DG Research & Innovation of the European Commission, who implemented all the editorial requirements.

Joachim Szodruch
Dietrich Knörzer

Contacts:
Dietrich Knörzer (dietrich.knoerzer@ec.europa.eu)
Joachim Szodruch (Joachim.szodruch@dlr.de)

This page intentionally left blank

Forewords

Aeronautics and air transport are key industries for Europe, in which public and private stakeholders provide world leadership and help to meet society's needs by ensuring the sustainable mobility of passengers and of freight. These industries help to generate wealth and economic growth, provide highly skilled jobs and innovation and foster Europe's knowledge economy through substantial R&D investments.

If Europe is to maintain its economic strength in the future, it needs to evolve into a true Innovation Union where knowledge can be shared freely across borders, and where synergies between research and industry contribute to increasing our global competitiveness. This is especially true for the air transport and aeronautics sectors, where their success is dependant on a high degree of research and innovation.

Ten years ago the Vision for 2020 was developed for European aeronautics; it successfully gave guidance to setting priorities for research and technological developments at European, national and industrial level.

The time had come for a new Vision, which was presented at the Sixth European Aeronautics Days 2011. This conference brought together researchers, engineers, managers and policy makers active in the field of aeronautics and air transport from all over Europe, and the world.

Aerodays 2011 inspired specialists to look beyond their particular field, and inspired generalists to take advantage of the presence of expertise in key aviation technologies. Together they will come up with solutions for tackling some of Europe's most pressing challenges by creating a highly competitive aeronautics and air transport industry for Europe which is greener, safer and more secure.

Máire Geoghegan-Quinn
European Commissioner for
Research, Innovation and Science

Siim Kallas
Vice-President of the European
Commission and Commissioner for
Transport

Air transport has transformed society over the past decades. (Economic and social benefits have turned aeronautics into a strategic industry for the prosperity of Europe and have strengthened Europe's position as a global player.) meaning unclear?

Currently, the main challenges for Europe are to get a more secure, safer, and more efficient air transport system, sustainable from both an economical and environmental viewpoint.

The Sixth Aeronautics Days 2011 presented the perfect framework to discuss how to meet these goals and how to emphasize the critical role that research and innovation has to play. It fostered cooperation amongst the main aeronautical stakeholders worldwide and offered an outstanding occasion to present the new Vision 2050, a document which explained the guidelines to be followed by the industry.

Spain, as one of the main actors of the European aeronautics community and a proactive member of the European Research Area was delighted to have hosted this new edition of Aerodays. This event was aligned with the ongoing national and European Union innovation strategies that focused on a research-intensive and innovative sector: the aeronautics industry.

Cristina Garmendia
Minister for Science and Innovation
of Spain (2008–2011)

Contents

Introduction to Part One
Policy and Strategy

This part provides the political messages delivered during the Aeronautics Days 2011 by senior representatives of the European Commission, Spain and the Region of Madrid addressing the key issues for research and innovation for Europe and its aviation. It also collects the views of several of Europe's biggest aviation stakeholders represented by their leaders, underlining their companies' perspectives for innovation and technologies for aeronautics industry, airlines, airport and research providers.

On the initiative of the European Commission a High-Level Group on Aviation Research representing the key stakeholders had developed the joint European Vision for Aviation 'Flightpath 2050'. Many plenary speakers, amongst them several members of this High-Level Group, addressed the goals of Europe's new Vision from their perspectives.

Part One is structured around two main categories of contributions: those which are oriented towards the necessity of innovation for a sustainable aviation in a global environment, and those dealing with the joint effort to be conducted in Europe with a view to preparing the future.

This page intentionally left blank

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-3

Keynote Address by Cristina Garmendia Mendizábal

Cristina GARMENDIA MENDIZÁBAL
Minister of Science and Innovation of the Government of Spain
(Between 14/04/2008 and 22/12/2011)

Abstract. Strong Spain's commitment to the Aeronautics sector: financial resources for innovation, public procurement, internationalisation of innovative activities, cooperation among public administrations, incorporation of innovative talent into national aeronautics companies.

Keywords. Science, technology, innovation

It is my great pleasure to welcome you to the Sixth European Aeronautics Days, "Aerodays 2011". As you know, this Conference is an event organised by the European Commission and the Spanish Ministry of Science and Innovation. First of all, I would like to take this opportunity to thank the European Commission DG Research and Innovation for organizing this Conference jointly with our Ministry. I would also like to express my gratitude to all of you – especially to the Sponsors and Collaborators – for honouring us and being part of this meeting to discuss and to understand the key role of "Innovation for Sustainable Aviation in a Global Environment".

On a day like this on which Aerodays 2011 is taking place, more than thirteen million [1] people will be flying on airplanes all over the world – nearly four million of them in the European Union. Many of these flights will use major airports. In Europe, for example, London, Paris, Frankfurt and Madrid will have the greatest passenger traffic [2]. The rest of the flights will go to many other destinations, up to a total of 200,000 take-offs and landings worldwide, before the day is over.

And the most surprising fact is that these figures will triple in less than 40 years, as air traffic in Brazil, Russia, India and China reaches the levels that are now usual in Europe and the USA.

With the current figures on the table and, especially, with these prospects for the future, no one can question the strategic nature of the aeronautics sector. A sector that, today, is generating in Europe more than 400,000 direct jobs – 35,000 in Spain – and a turnover of over 100 billion Euros per year.

But, above all, it is a sector on which we all depend much more than we imagine, until situations such as the eruption in 2010 of the Icelandic volcano Eyjafjallajökull become a drastic reminder.

This dependence on air transport – common to all advanced societies and economies – constitutes an opportunity for the aeronautics industry but also poses new challenges, such as optimising logistics operations, reducing environmental impact, energy saving and developing safer and more efficient technologies.

All these challenges can only be addressed through ever greater effort in Research and Development activities. An innovative effort that has been – if I may say so – part of the "DNA" of the aeronautics industry from the outset.

In Spain, for instance, the industry's R&D activities mobilize resources amounting to nearly 15% of the sector's turnover, and employ nearly 6,000 researchers and technologists. Public administrations, with their threefold role of regulators, procurers of goods and services, and promoters of R&D, have great responsibility in boosting this sector and, most especially, in its technological development.

That is why the Government of Spain, and in particular the Ministry of Science and Innovation, considers that events like the one we are having the opportunity to host are of the greatest interest.

Bearing in mind the current and future significance of air transport, two attitudes are possible: that of those who wish to lead, and that of those who prefer to follow the leader.

Neither Europe nor Spain can settle for being mere consumers of aeronautical technology. We can and we must participate, and, whenever possible, play a leading role in the successive innovations that will revolutionize this sector in forthcoming years, and the appropriate public policies can help us take on that European leadership.

We must also pay very close attention to the needs of an industry that will increasingly have to take decisions regarding where to make future investments. We must continue working to consolidate Europe as a preferential location for aeronautical research on a worldwide scale, and also to attract to our lands the other production activities in the sector's value chain, which are a source of stable, quality jobs.

In Spain we are certainly convinced that this is the way forward, and we consider the aeronautical sector a great ally, a strength, in transforming our economy and, now that we are addressing our recovery, in consolidating a more sustainable growth pattern, one that is more based on activities with high added value, such as those of our aeronautical sector, which is among the greatest in Europe and which has continued growing in terms of employment and turnover despite the crisis.

We know that the challenge is complex, but innovation has already taken pride of place on the Spanish political agenda, and we have been working intensely in the last three years to replicate in other sectors the technological leadership we have already achieved in some niches of the aeronautical sector, and in the field of renewable energy, to name just two examples.

Spain has, on other occasions, met equally difficult challenges. In the field of science, for example, our country has risen, in less than three decades, from a modest position on the world ranking – number 30 – to become one of the top ten countries producing science. Only yesterday we read a report by the Royal Society placing us, for the first time, ahead of Russia in volume of scientific production, and ahead of Australia and Switzerland in the quality of our science. We have achieved this by increasing the number of researchers by 36% since 2004, and by doubling the public budget we dedicate to research. This commitment has been supported by the private sector, with increased budgets for R&D, which have been for several consecutive years among the highest in the OECD.

And to transform all this scientific potential into economic development, we have, in recent months, promoted two major reforms in the field of science, technology and innovation. A new Law, which has received unanimous parliamentary support in the Congress of Deputies [3], and a National Innovation Strategy which, due to its approach, is a first in Europe, involves the entire Government, and focuses on five lines

of action: A financial environment favouring innovation; promotion of innovation from the standpoint of public procurement; internationalisation of innovative activities; co-operation among public administrations and, finally, employment, with different actions aimed at accelerating the incorporation of innovative talent into Spanish companies.

The National Innovation Strategy will lead to important strengthening of the aeronautics sector. We wish to support, with all the instruments available, a sector that has been able to grow in employment and turnover during 2009 – a year marked by the economic crisis – and which can now be a significant lever for recovery: because of its direct impact on our economy, of course, but also because of its capacity to successfully transfer its technology to other industries, thus increasing their competitiveness.

In Spain we have interesting experiences in this respect. For example, the application of composites originally designed for aeronautical applications to other means of transport and to renewable energies; the application of air communications equipment to railway use; and the use in the bio-health sector of certain sensors developed by our aerospace industry.

To conclude, I would like to once more insist on Spain's commitment to the sector, as well as on our great satisfaction at hosting this sixth edition of Aeronautics Days, which is being attended by more than 1,400 professionals from companies, universities and research centres in over 45 countries, to whom I reiterate my warmest welcome and my gratitude for their participation.

References

[1] ACI World Airport Traffic Report, 2009.

[2] Madrid ranks fourth in the EU and eleventh in the world in passenger numbers (ACI World Airport Traffic Report 2009).

[3] The Science, Technology and Innovation Act has been published in the Official Spanish Gazette (Boletín Oficial del Estado) on 2 June 2001, after receiving nearly unanimous definitive approval in the Congress of Deputies on 31 May 2011.

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-6

Keynote Address by Siim Kallas

Siim KALLAS
Vice-President of the European Commission and Commissioner for Transport

Abstract. The European Commission has launched a demanding innovation process in air transport and aeronautics in Europe. It has to complete what it has been started and to look beyond immediate concerns and to build further on its commitments. The report 'Flightpath 2050 – Europe's Vision for Aviation' was introduced, a basic document which has been established by a group of high-level representatives from the European aviation industry. The new White Paper 'Transport Road Map' was also presented. Technology and innovation are key-solutions for the future.

Keywords. Flighpath 2050, transport road map, SESAR/NextGen partnership

I am delighted to be here with you today and I thank Ms Cristina Garmendia and the Ministry for Science and Innovation and its agency CDTI for organising this important conference with the European Commission. The presence of so many participants from all stakeholder groups, policy makers as well as industry representatives and researchers, shows that we are at an important crossroads.

Aviation has had a decade of ups and downs, but overall it has been a tremendous success story for Europe. This would not have been possible without the sector's splendid ability and readiness to adapt to a changing environment, to innovate, and to take risks.

But we are not yet where we need to be. We still have to achieve our ambitious 2020 targets and the longer term future will bring even more demanding challenges. We need to be prepared. More importantly, we in Europe need to be ready to lead the change.

Firstly, we need to complete what we have started. We have launched a demanding innovation process in air transport and aeronautics in Europe and we need to deliver. This conference offers you a comprehensive snapshot on the ongoing research activities and their achievements so far, and I am pleased to see so much interest also from representatives outside the European Union. As they say, we vote with our feet! I take this as a positive signal that we are on the right track.

Secondly, it is time to look beyond immediate concerns and to build further on our commitments. 2050 looks far away but in the time scales of innovation, development and deployment, this is tomorrow. And we have a serious issue to address. Air traffic management still operates today with technologies which were developed in the middle of the last century, and unsurprisingly we face a lot of congestion and delay as a creaking system tries to accommodate ever rising demand. Meanwhile, we are now investing in the aircraft which will be flying well into the 2030s and longer – but we face more and more uncertainty about whether we will have sufficient conventional fuel to supply all transport needs. Aviation also needs to reduce its impact on climate change, of

course. New markets are emerging with new competitors as well as potential partners. Safety and security remain top on the agenda.

That's why we need a new vision of how to address these many challenges.

Earlier this week, on Monday, the Commission published its new Transport Road Map for the European Transport Policy, and you will find aviation prominently included.

Today I bring you the new European vision 2050 from the industrial, research and innovation perspective. The report "Flightpath 2050 – Europe's Vision for Aviation" has been established by a group of high-level representatives from the European aviation industry which I invited, together with my colleague Maire Geoghegan-Quinn, Commissioner for Research and Innovation, to look at the long term needs for aviation.

Why is this so important? I am sure I don't need to tell you. But aviation counts. It brings together a diverse aeronautics industry and supply chain of strategic importance, a marriage of large and small enterprises across Europe and beyond. And transport is vital not just to our personal mobility and freedom, it is central to our entire economy. Transport – and air transport – is not just a business: it must deliver for citizens and business.

To illustrate with an example: the Single European Sky and SESAR.

SESAR, the Single European Sky air traffic management research programme, of course is the European public-private partnership to prepare the modernisation of the air traffic management infrastructure. The SESAR Joint Undertaking manages this well organised programme for research, development and validation, involving many of you. However, we cannot rest there. We need to go one important step further. We need to implement and deploy. We need to get the successful developments to the market. This is one of my core priorities.

It is not just the lessons we must draw from last year's ash cloud crisis, from the snow of last winter. We have to tackle the constant grind of daily aviation delays, which everyone in Europe has to endure. This defines how passengers, how our citizens, our voters will measure our success. And of course, it is the fuel savings, the additional transport services, the overall costs (and by the way, the additional emission reductions), which will be the proof of the pudding for service providers.

We have a clear commitment of Member States at the political level to this vital project. The Single European Sky integrates regulation, performance targets, technology, the human factor and infrastructure. By 2014 we will realise savings of more than one billion Euros, and CO_2 emissions will be reduced by 500,000 tons a year starting 2012.

But let me also highlight the role of stakeholders in this context. You are the ones who will make it happen. You are the ones to benefit, but – it is also true – you will also carry much of the risks. So it is doubly useful to hear your views at this conference.

Let me not bypass the essential international dimension. We have just signed the EU-US Memorandum of Cooperation on civil aviation research. At the moment we have the opportunity together with the United States to show the world what a good SESAR-NextGen partnership can deliver. Interoperability is the watch-word – and this is not just a technical term. For airlines it means paying or saving millions, if not billions of Euros, and setting high quality global standards will provide new market opportunities for our industries.

There are also other programmes to complete: for example the Clean Sky Joint Technology Initiative which is an important element in our efforts to reduce CO_2 emissions. And of course the massive ongoing efforts in other research projects and initia-

tives from the Framework Programme which will be presented during the three days of this conference.

In addition, we also need to be prepared for the unexpected, look beyond our ongoing programmes and be open for innovation, also from other sectors such as energy, information and communication technologies or materials.

The Vision 2050 describes the main challenges for aeronautics and aviation. It sketches a scenario of the future and it proposes concrete goals for European industry and technology performance which will need considerable efforts in research and development.

I would like to invite you to read the Vision 2050 and the Transport Road Map, our new White Paper, carefully. They set the frame for the next steps to take. I invite you to work together to make it a reality.

Technology and innovation are key to the solutions for the future. The expectations are high and whatever we do or do not do, our actions will have a long lasting impact.

I am pleased that the Aerodays 2011 will again show that our strength lies in our combined efforts and our ability to connect with partners across the globe.

I look forward to hearing a detailed account of your deliberations over the next three days, and I hope you all benefit from enjoyable, interesting and lively discussions!

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-9

Keynote Lecture on Preparing the Future of Aviation – A Joint Effort of Europe

Máire GEOGHEGAN-QUINN
European Commissioner for Research and Innovation

Abstract. Europe needs to keep its place in the skies to keep its place in Europe. Two parallel objectives are presented in 'Flightpath 2050': the first in maintaining global leadership, the second is serving society's needs. They are closely interconnected because this is only by serving society's needs that we will be able to keep a position at the forefront of the global economy. A new instrument has been proposed to bring together all the relevant EU instruments: the 'Common Strategic Framework for Research and Innovation Funding'. This will allow put in place truly crosscutting strategies covering the whole innovation system, from research to technical developments, to demonstration and market uptake.

Keywords. Flightpath 2050, innovation emergency, innovation union, Europe 2020 strategy, common strategic framework for research and innovation

I am delighted to speak to you today at the sixth European Aeronautics Days. The theme for this year is "Innovation for sustainable aviation in a global environment". The subject is well chosen, since Innovation is at the very top of Europe's political agenda, and aviation has always been about innovation.

Since I became the European Commissioner for Research, Innovation and Science, I have met many of the leading representatives of Europe's aviation industries. I am convinced that the constant advances made in European aviation are often the result of the kinds of ideas and practices that we need to implement more widely in Europe – so that the European Union will become a world-leading hotspot for research and innovation.

At the heart of the Europe 2020 Strategy adopted last year by the EU Member States is the conviction that we need to innovate to get Europe back on the path to growth and jobs. And if the European economy is to take off again, we need everyone on board, everyone participating, Member States, the EU institutions, policy-makers, business-actors, the public sector, and of course researchers and scientists.

And besides the economic rationale, we need more innovation to tackle the major societal challenges faced by Europe, such as sustainable mobility, climate change, energy security or our ageing population.

The Innovation Union Flagship launched last October is our response to Europe's "Innovation emergency". It contains a programme of bold and necessary actions and policies to transform Europe into an "Innovation Union".

The Flagship underlines an idea that the aviation industries have long put in practice: that we need constant innovation to capitalise on new opportunities and tackle new challenges.

Sustainable aviation has a key role to play in addressing several of these challenges. First of all, we need aviation to keep our economy moving. We have seen very clearly the immediate economic effects of air traffic disruption caused by the volcanic ash cloud over northern Europe last spring and of the adverse winter conditions a few months ago.

Secondly, aviation industries have a key role to play in addressing the environmental, energy and resource challenges that we face. Aviation makes the world smaller. It brings people together, it enriches our outlook. But with that also comes the responsibility to minimise aviation's impact on the planet and on people.

The aviation sector is crucial for Europe: you provide 400,000 jobs, many of them highly skilled; you invest at least 12% of your turnover in R&D; and about 60% of your production is exported outside of our continent. Passenger traffic is growing by some 4 to 5% per year and Eurocontrol expects that by 2030 air transport in Europe will almost have doubled compared to today.

That's a lot, but the growth of passenger traffic is even higher in other regions of the world! That is why we need Europe to take a competitive position to provide aircraft and aeronautics services not only for our own market, but worldwide. Europe is already a world leader, but we need to constantly innovate to secure our position and to do even better.

Europe needs to keep its place in the skies to keep its place in the world.

So it is vitally important to meet the Innovation Union goal of completing the European Research Area by 2014. This will create major opportunities for closer cross-border co-operation and cross-fertilisation of ideas and knowledge between researchers, universities, research centres and industry that are currently being lost because of obstacles to the movement of ideas and people.

But of course we should not stop there. A global industry such as aviation needs a global outlook – and I think I have already heard some Russian and Chinese in the corridors. The Innovation Union Flagship recognises the benefits of working better with our international partners. This means access to our R&D programmes, while ensuring comparable conditions abroad. This also means adopting a common EU front where needed to protect our interests.

While we are thinking in terms of at least ten years into the future with Europe 2020, the aviation industry is used to thinking in the longer term. With such long life cycles in aviation, what we are dreaming about today may only take to the skies in 20 or 30 years time. In that sense, the report "Flightpath 2050 – Europe's Vision for Aviation" that has been launched during Aerodays 2011 is not about an abstract future. We – researchers, industrialists and policy makers – are quite literally forming the future today.

Two parallel objectives are presented in Flightpath 2050: the first is 'maintaining global leadership', the second is 'serving society's needs'. To me, these are closely interconnected. Only by serving society's needs will we be able to keep a position at the forefront of the global economy. And again, this is in tune with the overall goals of Innovation Union.

Flightpath 2050 is an excellent policy document. It is the result of a great deal of much-appreciated hard work and – quite literally – of "blue sky" thinking. But this is just the beginning, we need to turn the vision into reality through excellent Research and Development and cutting edge innovation. The challenges and the opportunities are immense, and I hope you are as keen as I am to get down to work.

It will be essential to have the whole European aviation sector involved. The Strategic Research Agenda that the ACARE Technology Platform has prepared on the basis of the previous Vision 2020 has already become an important reference document. Now is the time to build on the success of ACARE and develop a new strategic roadmap for aviation research, development and innovation.

The real worth of having such a roadmap is that public and private funding programmes all across Europe can build on it when establishing their own priorities.

And we will have the greatest chance of success if it has been drafted with the full participation of all the relevant European stakeholders. Not just those working in the private sector, but also those involved in Member States and at the level of the European Commission. Not only because a broad consensus will help to realise the Vision, but also because the research roadmap will benefit from involving as many different expert views as possible.

It is clear that we can only achieve real progress by joining national forces together. This does not mean just joining forces across borders, but also across the sector. That includes the full participation of operational areas like airlines and airports, since for the general public these are the real interface, the most important points of contact with aviation and aeronautics.

It is probably true to say that most passengers will not be particularly aware of the technical attributes of their aeroplane. For most people, flying is all about their experience at the airport, the service offered by their airline, and how secure and comfortable they feel in the aircraft.

While I am committed to developing a new research, development and innovation agenda for aviation, we have already done much to support aviation research at the European level. The outcomes of this research are making a significant contribution to our Innovation Union goals. I would like to give just a couple of examples of the added value of aviation research at the European level.

European funding is helping to build collaborative links in the industry: an example is the ALCAS (Advanced Low Cost Aircraft Structures) project which brings together 59 highly specialised research institutions and enterprises from a wide range of technological backgrounds. They are working together to reduce the weight, and thus the fuel consumption, of aircraft. It is the bundling of their expertise that makes it possible to think about ways of using composite materials throughout the whole aircraft, where each component poses its own particular challenges.

As the Innovation Union emphasises, by encouraging new ways of working together, we really can arrive at out-of-the-box ideas, and true innovation. In the TIMPAN (Technologies to ImProve Airframe Noise) project on noise reduction, an out-of-the-box idea came from a Romanian SME participant that was not part of the big, established organisations. It proved to be the most promising idea of all, eventually leading to a joint patent with Airbus.

The European Union is committed to supporting aviation research. Under the 7th Framework Programme, the European Commission has already invested over 500 million Euros in more than 200 different research projects. We have also committed 1.5 billion Euros for the Single European Sky (SESAR) and Clean Sky initiatives.

Since the aviation industry is one of the Framework Programme's most important customers, I expect you, therefore, to make an active contribution to the public consultation on the follow up to the current 7th Framework Programme, which will come into force in 2014.

European research funding is currently spread across too many small programmes and different instruments, sometimes with insufficient scale and scope to make real breakthroughs in a visible way – especially in large scale, expensive technologies such as aeronautics. Getting better value for money also means cutting red-tape, so that EU-funded scientists can spend more time in the lab. We cannot attract the most brilliant scientists and most innovative companies with an incoherent set of funding instruments, with complex and bureaucratic rules.

So, I have proposed a new instrument – a Common Strategic Framework for research and innovation – to bring together all of the relevant EU instruments. This will allow us to put in place truly crosscutting strategies that cover the whole innovation system, from research to technological development, to demonstration and market uptake. It will help ensure that excellence remains the byword for European research.

I recently published a Green Paper to launch a public consultation on key questions for this Common Strategic Framework. I encourage all of you to take part in this debate. Your views will be crucial for the Commission in developing its legislative proposal on the Common Strategic Framework by the end of this year.

I truly hope that Flightpath 2050 will motivate us and push us all to achieve by 2050 the challenging and ambitious objectives that have been set out. These will benefit not just the aviation sector, but also millions of people whose lives are enriched each and every day by the freedom of travel. I am personally committed to help Europe meet these goals through the proposed Common Strategic Framework for research and innovation funding.

Together, we can make Europe's Vision for Aviation a reality.

And together, we can make air transport ready for the future – a future in which aviation and aeronautics continue to prove that, as far as European innovation is concerned, the sky really is the limit!

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-13

Inauguration Speech by Eva Piera

Eva PIERA
Vice Minister of Economic Affairs of the Regional Government of Madrid

Abstract. Madrid: a regional actor of the European Aeronautics Community.

Keywords. Madrid, Nereus Network

Introduction

Madrid is one of the main regional actors of the European aeronautics community and a proactive member of the European Research Area. Aeronautics and air transport are key industries for Europe, in which, public and private stakeholders provide world leadership and help to meet society's needs in terms of sustainable mobility of passengers and freight. But what's very important as well, these industries are key drivers in Europe to generate wealth and economic growth, to provide highly skilled jobs and to support innovation system with substantial R&D investments.

As appears in the Europe 2020 Strategy[1], if Europe is able to maintain its economic strength in the future, it needs to evolve into a true Innovation Union where knowledge can be shared freely across borders, and where synergies between research and industry, contribute to increase our global competitiveness. And this is especially true for the air transport and aerospace sectors.

Ten years ago, the Vision for 2020[2] was developed for European aeronautics; it successfully gave guidance to setting priorities for research and technological developments at an European, national and industrial level. And in the Madrid Region we used these general guidelines to define our own strategy, fully aligned and integrated within those parameters.

Now, we have the opportunity to adopt a new Vision, which will be presented at this 6th European Aeronautics Days 2011[3]. A unique platform that bring together researchers, engineers, managers and policy makers active in the field of aeronautics and air transport, both in Europe and worldwide. So it is a unique platform.

1. A Bit of Madrid

The Madrid Region forming just 1.6% of the Spanish territory represents almost 20% of the national economy, and the income level is 29% greater than the EU-27 average. Also it is the main business, financial and political centre of Spain, with a very dynamic economy, that has reported an annual average growth of almost 2% in the 2005–2009 period of time.

Madrid's economy is particularly focused on the services sector, which generates more than 80% of the regional GDP, but has an innovative industry as 2nd engine of the economy.

40% of all IT companies in Spain are based in Madrid [1], along with 19.3% of all biotech companies [2], and 57.7% of the Aerospace sector turnover [3].

The Madrid Region hosts 270,000 workers in high-technology manufacturing and knowledge-intensive technology services, being the 2nd region in Europe according to Eurostat in high-technology sectors employment [4].

Each year 35,000 students graduated from any of the 15 Madrid based universities, of which 34% are formed in technical and experimental science schools[4].

The Madrid Region is the national leader in terms of expenditure in R&D, which represents 2.06% of GDP, above European average. It is actually the headquarters for 17 o the 19 Public Research Bodies which manage and execute main programs in the National Research, Development and Innovation Plan. But what's important as well, 28% of Spanish private expenditure on R&D is originated in Madrid.

Likewise, the Madrid Region has a network of clusters that promote 12 sectors that are strategic for the region, among which Aerospace is one of the most important.

2. Madrid Regional Actor of European Aeronautics Community

As a regional administration, framed by the European and Spain's political and administrative context, we are using all our strengths as a region and exploring all mechanisms to support innovation and competitiveness of our aerospace sector. This has allowed Madrid to be the most specialized region in high-technology industry, representing almost 60% of the Spain's aerospace activity (92% in the case of Space) and around 3% of the European aerospace activity.

We are pushing for all available resorts to make the whole industry community work together: private companies, research centres, universities, public administration, regulatory authorities and the European Commission. This collaborative framework is key for the future of Aeronautics and Aviation System in Europe and in our region it's represented by the Madrid Aerospace Cluster, one of the sponsors of Aerodays 2011.

Besides, our region is a founding member in the Nereus Network, and our cluster is also founding member of the European Aerospace Clusters Partnership Association (EACP).

It is important to point out that our region is one of the few regions in the world – and even countries- that can create an aircraft, from the design phase through all the valve chain: manufacturing, certification, commercialization and maintenance.

Nowadays, there is a need to set new priorities for an extended timescale towards 2050. We know that Aerospace is one of the most research-intensive sectors in Europe, and despite difficult times, more than 15% of its turnover is dedicated to Research & Development.

The Madrid Region is aware about the importance of this sector and the drivers to be set will need to contribute to a new sustainable and economic model in our country. And for that purpose, other challenges will need to be met securing financing for key new programs and technologies, giving access to top educational and training programs and supporting the role of small and medium enterprises (SMEs) in the industry sector.

For the industry as a whole, we know that a concentration on core competencies and high value-added activities will be key success factors. In this sense, one of the new leitmotivs for the future of the EU cohesion policy is the so-called "smart regional specialization strategy"[5]. The specialization will take place along applications exploit-

ing business segments, or markets that require adaptation of general technologies to specific user needs.

The regions that are not leading in any technological sector will have to increase their intensity of investments in the knowledge-based economy.

This smart regional specialization concept must be understood in three layers:

- a policy of different sectors, an eco-system supporting innovation, growth and job creation;
- an integrated approach through which an innovation eco-system supports high growth potential enterprises, sectorial niches and accomplishing expectations of the society;
- a plan to provide higher added-value services to all regional stakeholders.

And for these sense, we should never forget to support the development including start-ups and innovation, recruit new industry, talent and investors, diversify (product/service or geographical) existing industry, upgrade mature industry which already exists, improve R&D and innovation infrastructures and networks and promote strong partnerships with and within regions.

Finally, Madrid is trying to push each of those requirements and I want to express in this important industry appointment our commitment with the European Aerospace Sector.

Endnotes

[1] This is the EU's growth strategy for the coming decade. Concretely, the Union has set five ambitious objectives – on employment, innovation, education, social inclusion and climate/energy – to be reached by 2020. Each Member State will adopt its own national targets in each of these areas. Concrete actions at EU and national levels will underpin the strategy.

[2] In 2000, the 'European Vision for Aeronautics and Air Transport in 2020' was launched to meet the needs of our society, while maintaining an European global leadership in aeronautics. Since 2000 the perception of our society regarding air Transport has changed a lot and in the future 'Towards 2050', aviation is likely to face even more radical challenges.

[3] Aviation Platform's support for "Vision 2050", a long-term strategy for research and innovation in aviation is being developed by a group of European top-level representatives of the European aeronautics and aviation industry. They are working on a proposal for an ambitious research and innovation strategy to put Europe at the forefront of competitive, clean, safe and secure aviation by 2050, and members of the High-level Group on Aviation Research will present the "Vision 2050" at the Aeronautical Days 2011 in Madrid on 30 March to 1 April.

[4] INE: National Statistics Institute.

[5] Regional policy contributing to smart growth in Europe 2020.

References

[1] Penetración Regional de nueva Economía, CEPREDE, 2010.
[2] Annual Report, ASEBIO, 2010.
[3] Memoria, TEDAE, 2010.
[4] Eurostat, 2009.

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-16

Inauguration Speech by Rudolf Strohmeier

Rudolf STROHMEIER
Deputy Director-General Research & Innovation, European Commission

Abstract. Europe: the importance of the Aeronautics Sector, a common strategic framework in order to create a much higher impact and to simplify access, a new vision for aviation 'Flightpath 2050'.

Keywords. Europe, research, innovation

Introduction

As Bill Gates, former CEO of Microsoft once said: "The Wright Brothers created the single greatest cultural force since the invention of writing. The airplane became the first World Wide Web, bringing people, languages, ideas, and values together". When I see this audience in front of me today, with people from all over Europe, but also from China, Ukraine, Russia, South Africa, and the United States, I can only agree. Aviation does bring people together and this is also what the European Commission is encouraging with the Research Framework Programme of the European Union.

On behalf of the European Commission's Directorate General for Research and Innovation, I would like to warmly welcome you all to the Sixth European Aeronautics Days.

It is a true honour for me to be opening such a major international event which happens only once every five years and where the main European stakeholders of the aeronautics and air transport sector, both institutional and industrial are represented.

My colleagues from the European Commission and the Spanish Centre for the Development of Industrial Technology (CDTI) have put a lot of effort into making the Aerodays 2011 a success. I would like to sincerely thank all of them for making it possible to organise such a unique event.

1. The Importance of the Aeronautics Sector

Aviation – Aeronautics and Air Transport – is essential for Europe, not only for ensuring the economic links within Europe and beyond but also as an industrial area of strategic importance. The European Aeronautics sector represents more than 400,000 industry jobs, invests 12% of its turnover in R&D and exports about 6% of its production. Europe's Air transport is giving directly and indirectly jobs to about 4 million and represents 800 million passengers transported per year with a growth rate of 4–5% per annum.

We experienced recently the vital importance of the air transport system for Europe as well as its vulnerability when, almost exactly a year ago, in April 2010 a volcano erupted in Iceland. Millions of people were unable to fly, many of them were blocked far away from home and hundreds of thousands of tourist and business ar-

rangements were cancelled. The global supply chain of industry was severely affected. While we were still thinking ‘never again’, similar disruptions hit Europe when this winter heavy snow falls paralysed a number of major airports.

These events clearly demonstrated that air transport needs to be better connected with other transport modes, but also that further coordination is needed in Europe. We need to work on this together and the European Commission is committed to do so.

2. European Commission Contribution to Research

We have been spending over Euros 1.5 billion on more than 300 research projects under FP7, plus another 700 and 800 million Euros respectively to establishing a Single European Sky (SESAR) and financing the Clean Sky Joint Undertaking.

Just looking at the Aerodays programme and the number of parallel sessions gives you a flavour of how rich and diverse EU research projects are.

3. EU 2020 – Innovation Union

I would like to inform you briefly how the Commission is currently preparing the future of EU research.

The topic of today’s opening ceremony ‘Innovation for Sustainable Aviation in a Global Environment’ fits well into the Europe 2020 Strategy and in particular into its Flagship Initiative – Innovation Union.

The Europe 2020 Strategy fixes the objectives of smart, sustainable and inclusive growth. Seven flagship initiatives have been launched to contribute to this ambition. The ‘Innovation Union’ is one of them. It is a bold strategy which aims to put in place the conditions needed for research and innovation in Europe as well as mobilising efforts on some of the key challenges.

4. Green Paper Consultation

Of course, the European Commission cannot achieve this Innovation Union alone. You all have to provide us with your valuable input and you have a unique opportunity.

On 9th February 2011, the College of Commissioners adopted a Green Paper that launched an open consultation on DG RTD’s proposals for a “Common Strategic Framework”. This consultation is open to stakeholders until 20 May 2011. The results of the consultation will feed into a major conference to be held in Brussels on 10 June. All of you are more than welcome to provide your views and contribute to the design of an improved EU research and innovation funding programme because the results of the consultation will be an important input for the preparation of the Commission’s legislative proposals by the end of 2011.

5. Common Strategic Framework

What is the aim of this Common Strategic Framework? The idea is to create a much higher impact and to simplify access.

It should allow a coherent approach to strategic priorities. In the green paper we propose a focus on three strategic objectives:

- Tackling major societal challenges,
- Increasing competitiveness, and
- Raising the levels of excellence in the research base.

It should be designed to allow organisations and projects to move across the different stages of the innovation cycle so that good ideas get to market.

There should be more standardised rules across all parts of the Common Strategic Framework, so that participants do not have to learn a new set of rules each time they apply to a different programme. There should also be a common entry point and a rationalised toolkit of funding schemes, which removes confusing variations between current instruments.

6. Europe's New Vision for Aviation 'Flightpath 2050'

Regarding the aeronautics sector, a major contribution will be presented to you today: Europe's new Vision for Aviation 'Flightpath 2050'. I welcome this ambitious exercise and I am now looking forward to the next step, a new research roadmap that needs to be jointly developed with all aviation stakeholders.

It is based on the Vision 2020 for Europe's aeronautics announced 10 years ago. With its ambitious goals it gave guidance for research and technological developments on European, national and industrial level.

I trust that the Vision 2050 will be a new starting point for the aeronautics and air transport community to enabling the research and technologies to achieve the ambitious goals of the new common version.

7. Conclusion

When walking into this conference centre and going through the exhibition stands, I could see that you have developed a lot of bright ideas and promising technologies. I prompt you to visit the exhibition and to follow the numerous technology sessions. I sincerely hope that you will profit from the occasion of these Aerodays to exchange ideas and learn from each other's approaches and research projects.

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-19

Inauguration Speech by Antonio Vázquez

Antonio VÁZQUEZ
President, International Airlines Group (IAG) and Iberia

Abstract. The need for efficiency will lead to the coordination of different means of transport; environment is one of the major challenges affecting the growth of aviation industry; Air Transport will only be able to meet its emission reduction targets if sustainable alternative fuels are deployed.

Keywords. Airlines, operating procedures, new fuels

It is my honour to be here today sharing this tribune with such distinguished representatives from the European Commission, European Parliament, Member States, Spanish Ministry, Regional government and industry & research aeronautical institutions, etc. We could never find, sitting all together, a better representation for and in the interest of this industry.

Being the first airline speaker in this event, I presume I have also the responsibility and of course the need, to say what the expectations are from an airline perspective for the coming decades.

It seems difficult to predict today what is going to happen in 2050, but something we are very sure of is that the need of mobility for people, likely to reach 9 billion by then, will still be there and aviation will be the only viable direct way of connecting regions around the world.

In the coming years air transport will face one of the most radical changes it has faced so far. In a few year time, yet unknown, production of fossil fuels will begin to decline and by 2050 new fuels will be feeding our engines. Similarly, automation will be fully developed and the role of intelligent systems will be paramount in air traffic control increasing safety levels and flight efficiency.

In my view, this need for efficiency will naturally lead to the coordination of different means of transport as a result of which the present model in which our hubs are fed solely by aircraft will evolve into large intercontinental hubs fed by short haul aircraft and high speed trains. Alike, it will become common to have to transport groups in which surface and air transport are managed by the same corporation.

Certainly, this is the ideal world, but the fact is that, although technical and scientific progress can be traced linearly to human behaviour, this line might be quite unpredictable in this case as we cannot ascertain today how societies will react when fossil fuels become scarce whilst the now emerging economies will be matured and highly energy dependent.

Society and human behaviour has never changed as fast as now. Internet and satellite communications have played the role to broad citizen minds who are now more conscious of their rights than ever before and who no longer accept things as given. Airlines will no longer focus their strategies only in operations and customer care. We have started to look further to include in our folders also those social and human issues that will determine the new customer demands and concerns in the future.

Environmentally speaking, if we look back at 1991 when the first Aerodays summit took place, no one would ever think that environmental issues would be at stake as they currently are with ample discussions on the effects of human activities on global warming, laws limiting and penalizing those activities and large investments on Innovation & Development to minimize our footprint on the environment.

No doubt, environment is one of the major challenges affecting the growth of our industry, perhaps the biggest we have faced ever. The implications derived in searching that efficiency, affect every single area of this business. At this point we can raise our voices and proudly declare that among the different means of transport, aviation has been the most environmentally conscious. It has been the only one that, long before any other of our competitors were concerned by the environment, was obliged to seek efficiency in terms of fuel consumption and comply with stringent noise curfews.

Long before environment was an issue, our industry had adopted practices and taken measures to mitigate aviation carbon and environmental footprint. And today we are committed to keep on along a track that contributes to the economic and social development of our world. This commitment is our best ally because from now on no industry will have a future unless it is not environmentally sustainable.

Aviation is responsible for a very small part of man-made carbon emissions, roughly 2%. But the point is not if this share is low or not or if other modes of transport are less environmentally friendly, assuming our responsibility, aviation industry understands that as long as we are part of the problem, we should also be part of the solution.

For many years airlines, airports, air navigation service providers and manufacturers have being working to achieve the most aggressive climate change commitments never ever made by other industries. The sector has shown unprecedented support for a single vision to reduce emissions, setting targets that aim to improve by 1.5% our fuel efficiency annually from 2010 to 2020; a cap on net carbon emissions from 2020 through carbon neutral growth; and a 50% reduction in carbon emissions by 2050 compared to 2005 levels.

Huge investments will be needed to achieve this target. Just for European airlines, an investment of € 400 billion over the next 10 years will be needed to acquire 5,000 new aircraft.

We want to be a carbon free industry, and we have started to look ahead towards this objective. It is still a long way to cover but I think all the airlines have taken their responsibilities seriously by delivering already tremendous improvements to become efficient as soon as possible.

And this concern obeys not just to our will to reduce to the minimum our carbon footprint, but also to the need to reduce our costs in a really difficult time for airlines. In a moment when our cost structures are affected more than ever by external factors, we are desperate to find all possible alternatives available to move forward and reach our targets keeping profitability in the most efficient way.

We can play our part in this pathway and definitely that is what the airlines have been trying to achieve over the last years. The environmental protection has been a constant feature in Iberia for many years and is singled out as one of our corporate priorities:

- By renewing our fleet: As an average the new aircrafts that will be replacing older ones in the next two years, will reduce emissions by a 15% compared to the replaced aircraft.
- By adopting measures to reduce the weight of our aircraft.

- By adjusting the cruise speed in long haul routes, and optimising the assignment of fleets for different routes and fleet utilisation. Let me give you a brief example. According to our calculations, an Airbus A340/300 on the Madrid-New York route flying at an average speed of 402 knots could save practically 2 tonnes of CO_2 on the flight by lowering its speed to 397 knots, while the difference in time of arrival would be no more than 5 minutes.
- By promoting the introduction of new energy-efficient navigation and operating procedures.

But airlines alone cannot bring us to the greener world we desire. Additional measures from governments are needed to build that carbon free future we are all looking forward to. The world's governments must now take up the challenge by putting forward emission saving initiatives, such as air traffic control modernisation, and adopting a truly global approach to aviation and climate change. Also a coherent intermodal political planning at airports will provide a win-win situation in terms of sustainability and efficiency.

The current air traffic management system is inefficient and expensive in Europe. Although significant progress has been made, we are still far away from having an efficient air transport system. To get the maximum efficiency we need:

- Political will as a way of cooperation between countries and Government commitment to move on the consolidation of the airspace.
- Public funding will be needed to ensure the deployment of the new technologies and systems. To give a clue, it is estimated that nearly € 30 billion will be needed for the next SESAR phase, the technological tool of the Single European Sky project. Without these investments, the Single European Sky could be left in mere theory.

We need to find a common consensus in finding a workable global trading scheme for aviation emissions. Unlike emissions from automobile, chemical or electricity industries, international aviations emissions are extraordinary difficult to regulate. Regional regulations cannot easily be designed to cover an aircraft flying and crossing continents, countries and oceans away from its own regulating region.

And that is the case of the cap and trade system designed by the European Union by which the airlines will have to face a bill of up to € 1.4 billion per year. No complaints, the system, though it is probably an efficient way to cope aviation emissions, definitely better than taxes, could lead European airlines, if other third countries do not comply, into a complicated situation vis-à-vis our competitors from these regions. We support the development of an ambitious global solution on climate change and call the European Union, today present here through Mr Siim Kallas, to take a leadership role in agreeing in advance with third countries its implementation on the basis of consensus.

I cannot conclude my intervention, without referring to the alternative fuels and the recall that, air transport will only be able to meet its emissions-reduction targets if sustainable alternative fuels are deployed. Although we know these are not expected to become profitable before 2020 and this only if 15 billion Euros are invested, we call the Governments to establish as from now the right legal and fiscal frameworks to promote investment in low carbon sustainable alternative jet fuels. Without a real alternative to kerosene, airlines rely in bio-fuels as a mean of sustainability and future growth.

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-22

Special Lecture on "EU Vision 2050 – The Time Is Now" by Thomas Enders, Airbus

Thomas ENDERS
President and Chief Executive Officer of Airbus
Member of the High-Level Group on Aviation Research

Abstract. EU Vision 2050: the time is now. In 2050: 90% of European journeys will be completed in under 4 hours, flights will not be more than 1 minute late, Air Traffic Management will handle 25 million flights per year, we'll have reduced CO_2 by 75%, NOx by 90% and noise by 65%. SESAR must be correctly implemented. Bio-fuels development needs a carefully orchestrated collaboration, with clear reporting structures and clear responsibilities. Timing is everything. The success of the Vision 2050 comes down to determination, investment and timing.

Keywords. Bio-fuels, SESAR, NEXTGEN, timing

Introduction: The Challenges

We have just completed a global survey of 10,000 young people, who will be the passengers of 2050. Seventy percent of them expect:

- To fly more;
- In greener aircraft;
- The choice of quality, speed or luxury;
- And – of course – with access to all their gadgets.

The EU's Vision 2050 matches this demand. It's of an industry where:

- 90% of European journeys will be completed in under four hours;
- Flights will not be more than a minute late;
- Air Traffic Management will handle 25 million flights per year;
- And we'll have reduced CO_2 by 75%, NOx by 90% and noise by 65%.

Perhaps the only thing more difficult than deciding what gadgets people will actually have by then, will be delivering that vision – particularly while demand for air traffic doubles every 15 years.

By 2030 demand in North America, Western Europe and Japan will have grown by 80%, but account for less than a third of all traffic.

So how are we going to do that?

- With fuel running out;
- With much of the world's airport infrastructure already at saturation;
- With punitive taxes limiting our ability to invest in solutions.

And with all sorts of barriers to developing and sharing the talent needed to deliver them?

This is what I should like to talk to you about this morning.

Ladies and gentlemen, Vice President Kallas, Commissioner Geoghegan-Quinn, thank you for involving us the development of the European Vision 2050. On behalf of everyone at Airbus, our customers and our suppliers, we look forward to being just as involved in delivering the solutions.

I am also delighted that we can be part of Aerodays here in Madrid – just along the road from the Airbus Advanced Composite Centre in Illescas. We have 8,000 employees here in Spain and their expertise will be vital to delivering the Vision 2050.

1. Solutions

So what do some of those solutions look like and what actions must we take to deliver them?

1.1. Air Traffic Management (ATM)

As the world's population will have increased by 50% by 2050, perhaps we should start with air traffic management. If Europe gets its act together SESAR has the potential:

- To make life easier for air traffic controllers;
- To cut flight times for airlines and give more autonomy to their crews;
- And to reduce fuel burn by over 10%, benefitting the environment as much as the airlines.

Today SESAR is a plan, a vision. To be successful, it must be correctly implemented. That means it has to be performance driven and clearly separate the role of the industry driving it from the customers who will benefit from it.

- We need to replace procedures that have been around since before the jet age took hold;
  - Instead of just using technology to mimic existing systems we need new operational concepts that better integrate aircraft and infrastructure capabilities.
- In the meantime, we have to modify aircraft avionics within the next decade. Airbus and Boeing are already working on this – for both SESAR and NEXTGEN in the US, and to reduce fuel burn by over 10%, benefitting the environment as much as the airlines.
  - But we need the same effort from the teams responsible for air navigation services and ground infrastructure.
  - And we need significant investment from the government and federal authorities.
  - Implementing this ground technology goes beyond the financial means of the industry, but then, as it helps us to support more than 33 million jobs and almost 8% of GDP, so do the benefits.
  - Investment needs to come from transport budgets, not the R&TD budgets.

There's still a lot to do on SESAR. But if done right and we learn the lessons, it will show just how effective such co-operation can be.

1.2. Biofuels

We need to see more of this approach on alternative fuels if we are to combine local deliverables with global needs.

- On the one hand, the only way to secure enough biofuels for aviation is to use different feedstock in different regions, with processing and delivery infrastructure to match;
- But on the other, aviation operates to global certification standards, serving global customers and has a global environmental impact;
- And to reduce fuel burn by over 10%, benefitting the environment as much as the airlines.

Airbus cannot take the lead on this:

- Producing jet fuel is beyond our core business and is not where we add most value;
- Instead of that we can serve as a catalyst and a technical advisor;
- We aim to have at least one value chain project on each continent – like the new Spanish initiative we finalised this morning with Iberia and the Spanish Transport Ministry.

If we want to achieve a global solution, based on local resources, then we need carefully orchestrated collaboration, with clear reporting structures and clear responsibilities.

1.3. Timing is Everything: A380 & A320 NEO

The other thing worth noting about biofuels is that they represent an important next step in the way we power flight. They let us deliver benefits in terms of costs, emissions and availability until the entire industry is ready to make the massive leap to new power sources.

And that's trick for all of these goals – getting the timing right. Is it evolution or revolution? As the risk affects the entire industry, so must the benefits.

To give you a couple of examples:

- Take the A380. Undoubtedly a complete game changer, complete with all the risks I just mentioned – and a few more as it turns out!
  - For airport congestion and airlines "right-sizing" their fleets upwards to cut costs, the timing was right for the A380.
- Also look at the A320neo. In just five years the A320neo will be cutting fuel burn and emissions by 15% and operating costs by 8%.
  - Airlines can rack up the benefits while the game changer is developed.
  - Engine manufacturers can recover billions spent on the technology to deliver those savings and then reinvest to achieve the big leap we are all waiting for.
  - So if you want maximum benefit for minimum change, then the time is definitely also right for neo.

2. How to Reach the Objectives of Vision 2050?

Clearly, the success of the Vision 2050 comes down to determination, investment and timing.

- We know that people want to fly more, with more choice and less environmental impact;
- We know that we want to achieve this while giving an increasing proportion of the world's population access to the benefits that air travel brings;
- And we know that this industry can achieve a hell of a lot:
  - In the last 40 years we have cut fuel burn and CO2 emissions by 70% and cut the real cost of travel by 60% - enabling ten times as many people to reap the benefits.
  - In just the last decade demand for air transport has increased by 45%, but thanks to better operations and better aircraft, demand for jet fuel has increased by just 3%.

That success depends on our ability to find the best balance between different priorities– be it emissions, fuel burn, noise or costs. That takes lot of time, money and effort for work that will never see the light of day, but which is vital to identify the solutions we need.

So if we really do aspire to the Vision 2050 – then the time is now.

- We need investment. We need to leverage technology. And we need to stop squandering precious resources;
- Not in 5 years. Not in 10 years. Now.

The Vision 2050 is a wakeup call to ensure that Europe will still have a viable, competitive and sustainable aviation industry in the future.

- Airlines are upgrading to more efficient aircraft despite crazy margins, crazy fuel prices and even crazier taxes – ETS (Emissions Trading System) alone could cost the airlines some $4billion within the next decade, but who would have thought that any of these so-called environmental taxes wouldn't actually be invested in environmental solutions?
- Aircraft manufacturers and suppliers are investing billions in R&TD – some 12% of our turnover – despite one of the toughest economic periods in history – and without the kind of bailouts we saw other industries getting "in the name of the environment";
- Now the policy makers need to invest in unlocking and accelerating the technology, nurturing the necessary talent & removing the barriers to mobility that would let us deliver that vision.

Whether Europe is really serious about this we will be able to see with SESAR. It is the litmus paper. And that litmus test, ladies and gentlemen has to be taken now.

If we want to drive future technology, to protect the future of our planet and to develop the future talent that we need to make it all possible, then it's all in the timing.

And the time to invest in the success of Vision 2050 is now.

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-26

Speech by Johann-Dietrich Wörner, DLR

Johann-Dietrich WÖRNER
Chairman of the German Aerospace Centre – DLR
Member of the High-Level Group on Aviation Research

Abstract. The European challenges for aerospace are: global leadership and attention for societal needs; world class capabilities and facilities in research, test and validation as well as in education; clusters and networks; technological basis for European products; European and national programmes in competition and cooperation. To achieve these goals it is necessary to jointly define European research and innovation strategies by all stakeholders and to implement them in a coordinated way covering the entire innovation chain from basic research via technology development up to demonstration. A network of multi-disciplinary technology clusters should be created based on collaboration between industry, universities and research institutes. The DLR and DLR@UNI can be seen as a prototype of a new generation of links for research.

Keywords. DLR_Shool_Lab, DLR_Graduate programme, DLR_innovation_initiative, DLR@UNI

Today our global world faces a variety of challenges, ranging from climatic change, mobility, communication, energy and shortage of resources to conflicts and natural hazards. For the European aviation the future challenges consist of several aspects based on the increasing demand for mobility of passengers and goods. The basic demand is immediately followed by needs, formulated on the understanding of our Earth and its vulnerability: Aviation has to be sustainable and environmentally friendly (emission, noise). In addition we have to take into account the dependency on mobility in our daily demands characteristics such as efficiency, weather independence, resilience against crisis, safety and security. And all of these aspects are under the strong condition of raising international competition (Brazil, Canada, China, India, Russia, etc.).

Europe can face the broad variety of challenges successfully only when all stakeholders in aeronautics and air transport act in a coordinated common way on technical, organisational and regulatory level based on a broadly accepted common European Vision. Thanks to Vice President Kallas and Commissioner Geoghegan-Quinn the new European Vision for Aviation Flightpath 2050 had been developed by the High level Group on Aviation Research involving representatives from the aeronautics and air transport community. Flightpath 2050 covers education, research and technology as well as development and innovation.

The political statement of the vision asks for prioritizing research, test capabilities and education to maintain and develop the basis for success of Europe. The European challenges can be described so far by the following keywords:

- Global leadership and attention for societal needs;
- World class capabilities and facilities in research, test and validation and in education;

- Organisation in (regional) clusters and networks;
- Provision of the technological basis for European products;
- European and national programmes (competition and cooperation).

As a consequence it is necessary to jointly define European research and innovation strategies by all stakeholders, public and private. It is also necessary to implement all respective steps, in a coordinated way covering the entire innovation chain from basic research via technology development up to demonstration.

The success of European products must be based on a sound technological basis delivered through research on communication technologies, atmospheric research, new materials, manufacturing technologies, product life cycle engineering, new propulsion technologies, virtual certification and more. DLR, as one of the main European research stakeholders, intends to tackle all of these aspects by doing research from basic investigations to technology development. In addition we are eager to provide intellectual free space for the researchers to allow and to initiate creativity for future ideas.

In order to give synergy a sound basis the different research topics of DLR, namely aeronautics, space, transport, energy and security, realized within the other topics, are interlinked by the matrix structure of programmes and competencies, DLR owns its own plane-fleet to be able to do research with and at the planes. To do research with the planes means to use them for instance to observe atmospheric aspects, to monitor contrails and wake turbulences. When the volcano Eyjafjalla erupted in 2010, it was one of DLR´s plane, the Falcon 20E, which measured the density of the plume and gave the information to cancel the flight ban.

In addition to research performed by individual research stakeholders Flightpath 2050 asks for the identification, maintaining and continuous development of strategic European aerospace test, simulation and development facilities as well as the integration of ground and airborne validation and certification processes where appropriate.

Educational aspects such as attraction of students to careers in aviation, matching of courses offered by European universities to the needs of the aviation industry, its research establishments and administrations and evolvement according to changing needs and the establishment of lifelong and continuous education in aviation are also part of Flightpath 2050.

Finally we should create a network of multi-disciplinary technology clusters based on collaboration between industry, universities and research institutes.

The national research organizations do have a long history on European approach in research following or even forerunning European industry, shown by the creation of common infrastructure like DNW (Deutsch-Niederländische Windkanäle), ETW (European Trans-sonic Windtunnel). Concerning mutual organization of research the establishment of the Association of European Research Establishments in Aeronautics (EREA, 1994) managing roughly 380M€ per year in institutional civil aviation research has to be mentioned. In addition to that a number of bi- and multilateral joint programmes have been set-up such as DLR-ONERA helicopter programme, ONERA-DLR-Airbus Fixed Wing programme and DLR-NLR ATM-Research (AT-One). With the establishment of IFAR (International Forum for Aviation Research) a new international dimension has been initiated.

However we need to increase fundamental and revolutionary research in European aeronautic and air transport research and we need to educate appropriate work force for aviation. Further items in this respect are to enhance compatibility of European univer-

sity education and research and to create more institutional links between universities / research entities and industry (national and European).

The DLR model DLR@UNI can be seen as a prototype of a new generation of such links. DLR@UNI is not a strict rule but takes into account of the specificities of the regional cooperation between DLR institutes and other entities, namely technical universities. Cooperation in research, technology and teaching as well as joint activities in public relations, staff recruitment and development are central aspects. The well established DLR instruments DLR_School_Lab, DLR_Graduate_Programme and the DLR-innovation-initiative are additional elements to support the joint efforts as asked for in the new vision.

Flightpath 2050 can be seen as a successful first step on European level. Now it is time to make the next steps to realise the vision and to reach the goals by concrete measures. The promotion of ACARE in order to prepare the first strategic research and innovation agenda for aviation is one of these steps.

DLR and the whole research community organised in EREA, PEGASUS and EASN are ready to contribute to the new strategy process to finally realise a research and innovation friendly environment for Europe.

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-29

Speech by Giuseppe Orsi, AgustaWestland

Giuseppe ORSI
Chief Executive Officer of AgustaWestland
Member of the High-Level Group on Aviation Research

Abstract. The considerations addressed in 'Flightpath 2050' are shared by the entire Rotorcraft Community. The author's vision is this: by 2050, vertical flight shall be a mode of flying of a significant percentage of future aircraft, a portion of the continuum of flying activity. So, leveraging on vertical flight state-of-the-art technology will mean to improve mobility within and across our countries.

Keywords. Rotorcraft, vertical flight, helicopter

I am very pleased to be here in Madrid, contributing to an important event like Aerodays 2011, and to have the chance to share with the colleagues of the industry the opportunity to present the content of "Flightpath 2050", which brings to all European stakeholders a fresh Vision for Aviation towards 2050.

We have taken in great consideration the expectations of the European Union's Institutions and citizen's interests, in developing this Vision. We are certainly interested to progress our technology, so enhancing European industrial leadership. We have also acted on behalf of all stakeholders who look at us as those who can contribute to make everyone's life better. I assure you this goal is common to all of us who have participated to the elaboration of the Vision.

Most of the points have been touched by the other speakers. I am here to bring to your attention my personal considerations about the future of Aviation, and in particular in the field of rotary-wing and related technologies applied in the vertical flight field. Obviously the several considerations that have been addressed in the Vision, like the role and the specificities of this sector of Aviation, are shared by the entire Rotorcraft Community (industry, operators, end-users).

Today European rotorcraft industry can claim for global leadership, representing 50% of the market – civil and military; it becomes 60% if we include Russian helicopter industry. Furthermore, European companies have delivered 2/3 (two-third) of the total commercial helicopter fleets worldwide. Europe is ahead of United States. Stakeholders in rotorcraft field are well aware of this, but these figures have to be clearly stressed and communicated to public as well. This is a leadership based on clear strategies, industrial excellence, continuous innovation, human resources development and tight link with research and academia.

Looking ahead, towards 2050, we have to review and look beyond current rotorcraft concepts, and refer to a more general Vertical Flight Capability. Full exploitation of Vertical Flight is one of the major opportunities that Aviation has to add an additional degree of freedom in air transportation in a crowded world, and to make future intermodal mobility systems come true. In crowded areas we shall use the vertical axis in the lower space.

My vision is this: by 2050 vertical flight shall be a mode of flying of most part or at least of a significant percentage of future aircraft, a portion of the continuum of flying activity. The vertical take-off capability will move from military into civil aircraft. Future civil aircraft thus shall consider the optimisation of the amount of vertical flight vs. horizontal flight, their performance and flight envelope being dependent from the application. In the crowded areas of the world the vertical dimension of mobility will become soon a need rather than a choice, and we shall be ready.

With this respect, I shall vision a future in which the Vertical Take-off & Landing and the hovering capability will be available on machines that also have good forward speed, comparable to fixed wing speeds, and at the same level of comfort. Today, research in this area is already in progress in many industries that are working on new studies and architectures, flying prototypes, or developing new concepts of rotary-wing aircraft, advanced helicopter configurations, compound and tiltrotors.

Advances of vehicles are expected and possible in several areas of engineering, supporting R&TD research to introduce breakthrough technologies: active rotors, advanced materials (metallic, polymeric, composite, smart), streamlined low-drag design, active/passive systems for vibration and noise control, system integration, advanced avionics for flight & navigation, innovative propulsion solutions (more electric, hybrid configurations, alternative fuels), new enabling technologies, virtual simulation and full scale testing just to mention few of those areas.

We have to improve also the way we will effectiveness will come from satellites based navigation. Hence, flexibility, point-to-point connections, precision take off and landing capability, in all-weather condition, from a network of widespread infrastructures of airports – but also heliports and vertiports – even in crowded areas, are all fundamentals to empower the role of rotorcraft. In this context, unmanned capability will also be important, as it will take over a significant part of the routine Vertical Flight activities.

Acquiring new markets, maintaining global industrial leadership, fostering technological progress is not enough, for this must occur as a part of a wider frame in which the development of the European Society is the fundamental driver. Therefore, Aeronautics research and Aviation development shall devote attention to grow and to address their efforts in the environment and sustainability as well (emissions and processes through complete life cycle). Safety and security aspects will need direct investments, but they will also ask to be supported by strategic plans defined together with agencies and platforms that play relevant role in other areas (energy related issues, strategic transport policies, etc.)

Ladies and gentlemen if aviation is an invaluable asset for Europe, then vertical flight is a tremendous tool and portion of this asset, for the European Aviation Industry – where we are at the leading edge of innovation and leader in the world markets. And for us Europeans, leveraging on vertical flight state-of-the-art technology (noise, comfort, speed, range, sustainability, etc.) will mean to improve mobility within and across our countries, whose competitiveness is already being threatened by congestion, and to have a profound impact on our communities by improving our standards of living.

The members of the High Level Group and of the Technical Expert Group for Europe's Vision "Flightpath 2050".

Table 1. List of HIGH LEVEL GROUP Members

Name	Position / Organisation
Marek Darecki	CEO Wytwórnia Sprzetu Komunikacyjnego PZL Rzeszow S.A.
Charles Edelstenne	Chairman of the Board of Directors of Dassault Systèmes CEO Dassault Aviation
Tom Enders	CEO Airbus
Emma Fernández	Director General for Innovation, Talent and Strategy INDRA SISTEMAS SA
Peter Hartman	President and Chief Executive Officer KLM Royal Dutch Airlines
Jean-Paul Herteman	Président du Directoire SAFRAN
Michael Kerkloh	Vorsitzender der Geschäftsführung Flughafen München
Ian King	CEO BAE Systems plc.
Patrick Ky	Executive Director SESAR Joint Undertaking
Michel Mathieu	Senior Vice-President Avionics Thales
Giuseppe Orsi	CEO AgustaWestland
Gerald Schotmann	Chief Technology Officer and Executive Vice President Innovation/R&D SHELL
Colin Smith	CEO Rolls-Royce plc
Johann-Dietrich Wörner	Vorsitzender des Vorstandes DLR Deutsches Zentrum für Luft- und Raumfahrt

Table 2. List of TECHNICAL EXPERT GROUP Members

Name	Position / Organisation
Charlotte Andsager	Rolls-Royce plc
José Luis Angoso González	INDRA
Michele Arra	AgustaWestland – Innovation Projects Coordinator
Paul Bogers	SHELL
Vanessa Buhl	Flughafen München
Remy Denos	EC, DG Research Research Program Officer, Aeronautics
Mike Farmery	SHELL
Bill Giles	BAE Systems plc.
Robert Haligowski	PZL Rzeszow S.A.
Rolf Henke	DLR
Tiit Jurimae	EC, DG Research Head of Unit, Aeronautics
Axel Krein	Airbus
Michel Laroche	SAFRAN
Michiel Laumans	KLM
Fionna McFadden	SEASAR Joint Undertaking
Stefan Meier	Flughafen München
Uwe Möller	DLR
Doris Schroecker	EC, DG MOVE, Policy Officer, Research and Innovative Transport Systems
Solly Side	Thales Avionics
Bruno Stoufflet	Dassault Aviation
Luc Tytgat	EC, DG Energy & Transport, Head of Unit, Single Sky & Modernisation of Air Traffic Control
Simon Weeks	Rolls-Royce plc

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-32

Intervention by Domingo Ureña-Raso

Domingo UREÑA-RASO
President, ASD (AeroSpace and Defence Industries Association of Europe)
Airbus Military

Abstract. The ASD (AeroSpace and Defence Industries Association of Europe) represents the aerospace industry in Europe, which generates a turnover in excess of €100 billion and employs nearly a million highly-skilled European citizens. The ASD encourages European policy makers to: (i) create a dedicated funded aeronautics programme; (ii) ensure the stability of instruments recently deployed in FP7, Private Public Partnerships and joint Technology Initiatives; (iii) support the development of SESAR. How to turn Vision 2050 into a reality?

Keywords. ASD, industry, policymakers

I am delighted to be with you this morning, for the closing session of the Madrid Aerodays. As a Spaniard it is an immense joy for me to see the European aerospace family gathered on my home soil, for what has truly been a landmark event.

As President of ASD, the association which represents the aerospace industry in Europe, it is for me both an honour and a huge responsibility to speak on behalf of such an important sector. A sector, Ladies and Gentlemen, which generates a turnover in excess of 100 billion Euro, and which employs nearly half a million highly-skilled European citizens. I would like to start by expressing my gratitude to Commissioner Geoghegan-Quinn for the initiative she took, together with Vice-President Kallas, to convene a few months ago a High-Level Group on Aviation Research. We saw, on the first day, the result of the work done by this Group in the form of the report 'Flightpath 2050', which outlines Europe's vision for the future of aviation It is a remarkable document – and I am not saying this only to be nice to my dear colleague Jean-Paul Herteman, who was directly involved in its preparation I truly believe Flightpath 2050 is a remarkable document, in particular because it sets highly ambitious objectives for a Europe where, in 40 years' time:

- Flights will not be more than a minute late;
- Air Traffic Management will be able to handle 25 million flights per year (compared to about 9 million today);
- And we will have reduced, for each flight, CO2 emissions by 75%, NOX emissions by 90% and noise by 65%.

According to this vision, in 2050 Europe will also have proved able to preserve a strongly competitive aerospace industry – an industry which will have managed to retain more than 40% of the global market, despite the fierce competition coming from both established and emerging rivals. Ambitious goals then – which is fine by us, since over the last century our industry has certainly had a fine record in achieving ambitious objectives (objectives that many called 'impossible' at the time when they were set).

So, needless to say, we are keen to turn Vision 2050 into a reality, but how do we go about it?

For me, the answer is very simple: what is needed is substantial and sustained investment in technology and with that in mind, the next EU programme for research – the so-called Common Strategic Framework – will be a vital element in this effort.

As we all know, aeronautics is strongly driven by innovation. Our sector dedicates an average of 12% of its revenues to the funding of Research & Development activities, which is one of the two highest ratios across all industrial sectors in Europe. To give you an element of comparison, the automotive industry dedicates 5% of its turnover to R&D. This effort on R&D is absolutely vital for us, since new technology has always been the major competitive differentiator in world markets. This is even truer today, with the growing competition from new entrants such as Brazil, China, India and Russia. The European industry certainly cannot compete on price with these nations and has no choice but to innovate.

So we certainly do our share of the work when it comes to research funding. But we need support. Indeed aeronautics research is technology and capital intensive, and subject to very long cycles. Investments in technological innovation are therefore risky, and only bear fruit on a long-term basis. This is why financial markets are very reluctant to fund aeronautics research, and why public sector support is essential both at European and national levels. Backed by this public support – which, may I say, is common to all aeronautics powers worldwide – the aeronautics sector is in a position to co-fund research and innovation activities.

Over the last four decades, a lot of political courage and strong will have been necessary to propel the European aerospace industry to the top of the world's rankings. As an industry we acknowledge the political support which we have received, and we are certainly grateful for it. This being said, the realities of the situation which I have just outlined are such that this support is more necessary than ever.

Following the assessment of Simon Tilford, Chief Economist at the Centre for European Reform (a UK think-tank) and talking about European policies, he says that we need to increase the support for the development of new technologies as other countries are doing; the U.S. but also emerging aerospace powers such as China, provide more support for technology development. This is true, in particular, thanks to the cross-subsidisation of the civilian aerospace industry through defence spending, which is nowhere near as pronounced in Europe as in the U.S. for instance.

Let me be clear here: this form of cross-subsidisation is not a source of public investment which we call on European policymakers to develop. What we invite them to do instead is to work in close partnership with us, to ensure that new aerospace technologies continue to be developed and deployed in Europe, and to allow us to compete on a level playing field with other global aerospace players. For this we encourage European policymakers to:

- First, support the aeronautics thematic within the future Common Strategic Framework for Research and Innovation, with the creation of a dedicated funded aeronautics programme enabling Europe to meet its long-term objectives.
- Second, ensure the stability of instruments recently deployed in the 7th Framework Programme and which have proven their value (such as upstream pioneering research, technological integration projects, as well as Public Private Partnerships and Joint Technology Initiatives such as Clean Sky). At the

same time the efficiency of these instruments should be enhanced through a simplification of their implementation processes.

- And, last but not least, we call on European policymakers to support the deployment of SESAR, the future European air traffic management system.

These recommendations are included in an ASD Position Paper, “Aeronautics and the EU Common Strategic Framework”, which I invite you, dear Miss Commissioner, dear colleagues, to take a close look at.

Ladies and Gentlemen, aerospace has been, over the last 40 years, a great success story for our continent. But today we stand at a crossroads. Europe must choose between making the necessary efforts in R&D to maintain the leadership of its aerospace sector, or to stand still, taking success for granted, and being exposed to rising competition from emerging aerospace powers.

The aerospace industry and European policymakers need to work in close partnership to ensure the continuing success of our sector. Only with the support of public authorities shall we be able to continue delivering on key European priorities such as technological innovation and environmental sustainability. Only with that kind of support shall we be able to continue writing what has been a fantastic success story for our continent.

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-35

Airports – Suitable and Sustainable Gateways to the Globalized World

Michael KERKLOH
President and Chief Executive Officer – Munich Airport
Member of the High-Level Group on Aviation Research

Abstract. The paper "Airports – suitable and sustainable gateways to the globalised world" concentrates on several different strategies, based upon Munich airport experience, to meet the different future challenges for the airport industry: interconnected multimodal transport system, expansion of infrastructure, sustainable measures that will ensure that growth is largely achieved on a carbon-neutral basis, strategic system partnerships, support from the airport region.

Keywords. Airport, hub, passengers, Airport Carbon Accreditation Programme

Introduction

Flughafen Muenchen GmbH (FMG) operates Munich Airport, which opened at its current location in 1992. The new airport's strong growth rate – well above the industry average – raised it to join the ranks of Europe's busiest hubs within just a few years. FMG was formed in 1949, and is jointly owned by the Free State of Bavaria (51 percent), the Federal Republic of Germany (26 percent) and the city of Munich (23 percent). With nearly 35 million passengers in 2010, Munich retained its number seven position among Europe's top ten airports. The number of flights handled at the airport was approximately 390,000. The FMG Group, including its 14 subsidiaries, had total revenues of about 1.1 billion Euros last year.

With more than 30,000 people working at over 550 companies, the airport is one of the largest employers in the state of Bavaria. Statistically, if Bavaria were a country, it would rank 20th among the world's exporting nations. In view of Munich Airport's importance for Bavaria and Germany, the airport operating company has set an ambitious goal: "By 2015 we will be one of the most attractive, efficient and sustainable hub airports in the world".

The mission of the "High Level Group on Aviation Research" is tasked with "Formulating a new vision for the future of European aeronautics sector".

To successfully deal with the challenges of the future and ensure the competitiveness of the European aeronautics industry, individual strategies must be developed and implemented for European airports in general and Munich Airport in particular. In the interests of a successful "license to grow", the airport management is pursuing the following five key strategies:

1. A fully interconnected multimodal transport system is needed to provide affordable, reliable and seamless connectivity. Intermodal air-rail connections will provide a win-win situation in terms of passenger convenience and sus-

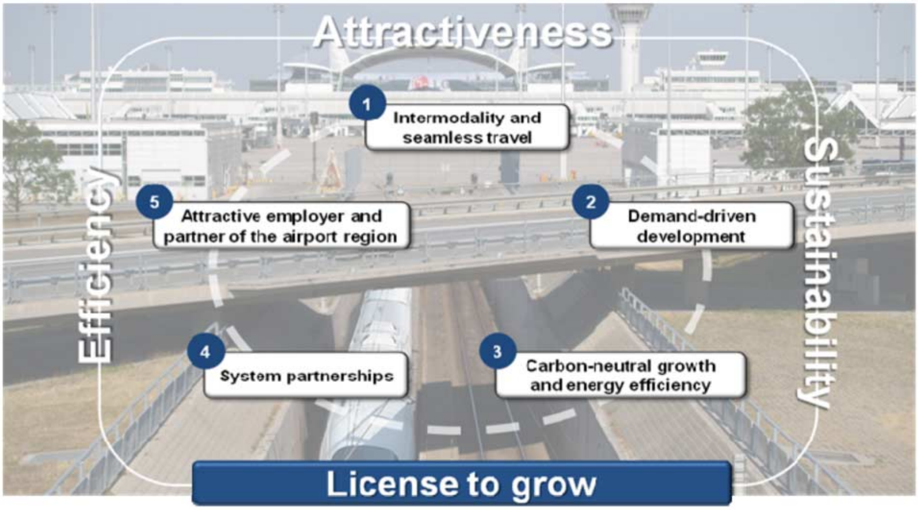


Figure 1. Key strategies of Munich Airport to meet future challenges.
Credit: Flughafen München GmbH

tainability. The implementation of security processes that are as non-intrusive as possible or result in only minimal interruptions and delays are necessary.

2. Expansion of infrastructure has to be in line with needs. An adequate ground infrastructure is necessary to mitigate delays and avoid congestion. Due to traffic forecasts for Munich Airport 58 million passengers will be reached in 2025. This volume cannot be handled without adding capacity to the runway system. Consequently, FMG is planning the construction of a new runway. The final ruling in the planning approval process for this expansion project is expected by the end of the year 2011. FMG also plans to expand its passenger handling capacity to meet increasing demand in the coming years. To achieve this aim, a satellite terminal will be built on the airport apron and linked to Terminal 2 by an underground transport system. The first phase of the satellite project will include the creation of 27 additional aircraft park positions adjacent to the terminal to permit passengers to board and disembark quickly and conveniently. The new facility will have an annual passenger capacity of 11 million, and is expected to go into operation in 2015.
3. The airport plans to implement its expansion projects and handle the increased traffic volume through sustainable measures that will ensure that growth is largely achieved on a carbon-neutral basis. For this long-term target a global network is necessary with minimal or no negative effects on the environment. It is a clear fact that air travel must reach the target to be environmentally sustainable in the future. One step to protect the environment is the use of sustainable energy. Also airports themselves can save CO2 while using new technologies, efficient infrastructure, optimized operations and economic instruments. Munich Airport proved already its efforts to become carbon-neutral and is today the first German airport, which achieved the “Optimization” level (Level 3) under the Airport Carbon Accreditation Programme.

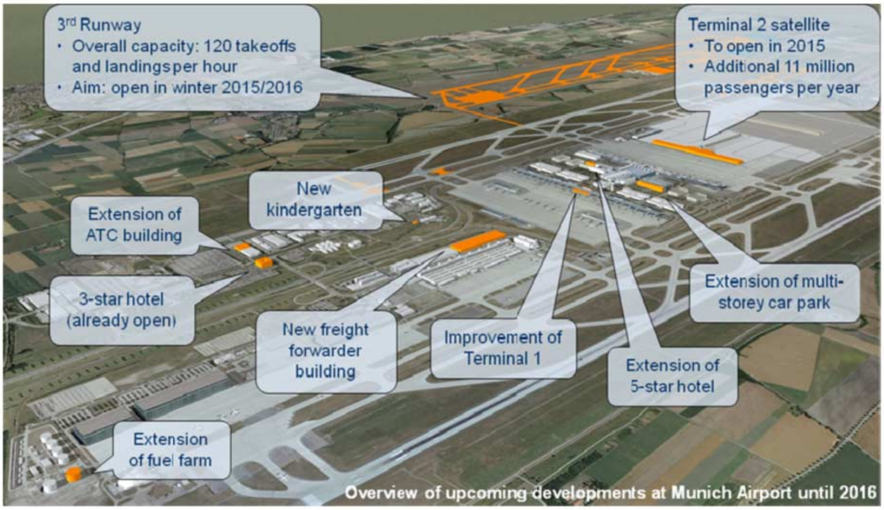


Figure 2. Demand-driven development.
Credit: Flughafen München GmbH

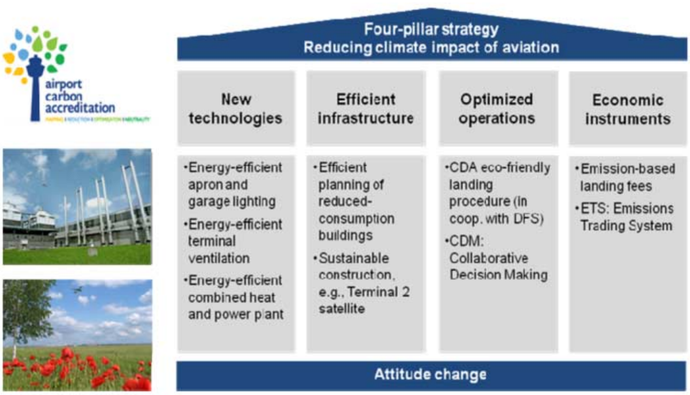


Figure 3. Instruments for reaching carbon-neutral growth and energy efficiency.
Credit: Flughafen München GmbH

4. Formation of strategic system partnerships is important for enhancing competitiveness. The most important growth engine for Munich Airport is the hub traffic of Lufthansa and its Star Alliance partners. These airlines in particular have played a decisive role in increasing the number of transit passengers using Munich Airport. They now account for 37 percent of total traffic. The close cooperation ensures competitiveness and a market-orientated development based on customer needs.
5. Acceptance of Munich Airport in the region has to be supported and strengthened. Offering attractive job opportunities and bundling regional forces as well as resources let the airport understand itself as a partner of the airport region which creates wealth in the region.

The feedback of travellers from all over the world reaffirms that we are on the right track. They value the outstanding quality of the passenger experience in Munich as well as the ease of making connections here. This has been confirmed again and again in the annual surveys by Skytrax, the London-based aviation research institute, in which passengers regularly vote Munich one of the world's top five passenger airports. On five different occasions – including the most recent survey in 2010 – Munich Airport has been voted number one in Europe.

Europe's airports will take numerous and very diverse measures in the coming years to successfully fulfil the vision for 2050. For this purpose, an efficient and effective policy backed by a corresponding regulatory framework will be indispensible.

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-39

The Future of Air Traffic Management

Patrick KY
Executive Director, SESAR Joint Undertaking
Member of the High-Level Group on Aviation Research

Abstract. The Single European Sky ATM Research (SESAR) programme is the technological pillar of the Single Sky European Initiative, founded by the European Union and Eurocontrol. Its role is to develop the new generation of ATM technologies and procedures to better cope with the predicted increase in air traffic over the next twenty years. This paper gives an update on this programme and concentrates on its importance for innovation in the aeronautical sector.

Keywords. SESAR, air traffic management, air transport, airspace, airport

Introduction

Air traffic management (ATM) technology is a peculiar affair. While relentless innovation has spurred spectacular progress in comparable fields of activity – such as information and communication technologies, software sciences or automation – the ATM industry appears to be stuck in a time warp. Whereas telecommunication solutions intended for the general public have leapt forward in terms of sophistication, power and user-friendliness, communications in air traffic management are still relying exclusively on VHF-radio, a technology that emerged in the first decades of the XXth century.

Modernisation has become inevitable, as ATM is facing unprecedented challenges: a continuous increase in air traffic that foreshadows a capacity crunch and the realisation that all human activities – including aviation – must demonstrate their long term sustainability in environmental, societal and economic terms. Unless we change the way air transport is managed, the European airspace will reach its maximum limits in terms of capacity, resulting in increased delays for passengers, higher costs for airlines and an increased environmental impact.

1. The SESAR Programme

The SESAR Joint Undertaking (SESAR JU) was set up in 2007 as a public – private body to manage the development phase of the €2.1 billion SESAR programme. It brings together 15 industry members representing all actors in air traffic management: the manufacturing industry (e.g. Airbus, Thales, Indra or SELEX Sistemi Integrati), airports (e.g. Frankfurter Flughafen, Aéroports de Paris, BAA Airports), and air navigation service providers (e.g. Deutsche Flugsicherung, Aena, DSNA). A further 25 associate partners including non-European companies (e.g. Boeing or Thales Australia), SMEs, universities and research institutes were taken aboard, to provide additional

input and expertise. In total, around 2,500 experts now are working together in Europe and worldwide on more than 300 interdependent projects aiming at lifting ATM technology to 21st century standards.

Additionally, the SESAR Joint Undertaking actively involves key stakeholders such as airspace users (e.g.airines); staff and professional associations as well as regulatory authorities or the military sector through ad hoc working arrangements. Through their early involvement in the work programme, the Joint Undertaking ensures that these stakeholders' needs and expertise are fully reflected in the final SESAR technologies and procedures. This makes the SESAR Joint Undertaking a truly international public-private partnership.

2. Delivery Approach

SESAR will dramatically change the way air traffic management is organised in future. Its work programme is organised in 16 work packages and roughly 300 projects which are executed in cooperation with SESAR members. These packages will develop and deliver the necessary operational and technical materials (specifications, procedures, prototypes, validation reports, etc) for the progressive industrialisation, deployment and operation of Europe's future ATM system.

To demonstrate the consistency and operational value of its work in progress, the Joint Undertaking and its members have developed the so-called SESAR Release approach. As of 2011, a list of projects ready for early validation and pre- industrialisation is approved and widely communicated. The SESAR approach is ground-breaking, because all technological improvements are directly verified in an operational environment and ready for deployment by European leading European airlines. The 2011 Release for example includes remote tower technology, satellite-based precision approaches, and additional automated tools for air traffic controllers. In 2012, the Release will concentrate on four main areas of operational improvements: airport platform safety, airborne operations, ATC operations and network management.

3. Bridging Innovation into Air Traffic Management

While the priority of the SESAR Joint Undertaking lies on delivering tangible, operational results for a modernised ATM system, it also dedicated one of its work packages (WP-E) to long-term and innovative research, to prepare the next evolution and bring about radical new ideas. WP-E concentrates on exploratory research aiming at identifying potential applications most likely to generate concrete benefits. This work will prepare the ground for applied research and development, leading to further advances in ATM that will become necessary, as traffic continues to increase while economic and environmental constraints continue to evolve.

The WP-E work package is structured around four themes: Legal Aspects of Paradigm Shift; Towards Higher Levels of Automation in ATM; Mastering Complex Systems Safely; Economics and Performance.

In that context, eighteen pioneering Research Projects have been launched so far. The Projects focus on specific challenges, explore innovative ideas and possible applications. They generate scientific knowledge which increases the understanding of ATM issues and demonstrates the potential of novel technologies, methods or concepts. SE-

SAR issues periodic calls for proposals, which are reviewed by a balanced panel of independent experts from industry, research and academic communities – and possibly awarded support.

The WP-E work package has also set up two very successful Research Networks, with some 400 participants worldwide, 25 PhD theses and highly successful conferences. A third Research Network will be launched during 2012. Research Networks are a key driver for technology leaps, as they bring together research groups, providing them with a structured framework to build up knowledge, competence and capability which will serve the industry in the long term. Each Research Network comprises members and participants from academia, research centres, industry and SMEs that share expertise and interest in a relevant air traffic management or transportation domain.

As SESAR as a whole is developing Europe's future air traffic management system, its pioneering arm in the WP-E work package is already expanding the boundaries of technology even further, paving the way for future advances that will make Europe's Single Sky a global role model for ATM achievement.

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-42

The Future of Aviation – A Joint European Effort

Rafael GALLEGO
Director General of Indra

Abstract. 'Indra', the Spanish IT leading company, committed to the EU programmes and SESAR in particular, is playing a leading role among the ground industry manufacturers in the domain of Air Traffic Management (ATM) and Airport technologies. Three elements have to be reinforced: cooperation between ANSPs (Air Navigation Service Providers) and ground technology suppliers, collaboration between ANSPs in major developments, partnership between the public sector and the industry.

Keywords. 'Indra', ATM, ANSP, European interoperability

Introduction

It is a pleasure for me having the opportunity to participate in this closing panel of Aerodays 2011, as spectator and in some way actor, of the impressive evolution of the use of the Information Technologies during the last thirty years in the Air Transport industry.

The new Vision 2050, presented by the Commissioner for Transport in the Opening Ceremony has been the highlight of Aerodays 2011. Since then, there have been various sessions to address the current status of various R&D initiatives as well as to discuss the status of innovation in the industry from different stakeholders' perspectives. In summary, it is widely shared that the European aeronautics and air transport industry needs to maintain or even accelerate its current level of innovation if it wants to maintain its competitiveness.

1. Europe Towards the 2050 Vision

This is not an easy challenge because the capability level is increasing in all geographical areas of the world. But my view is that we can live up to this challenge because we, the overall community are up to the endeavour. Europe is much better prepared now than it was a few years back. We are finding new ways to cooperate across countries and industry players: European Union, National Authorities, Regulators, air space users, airports and air navigation services providers (ANSP), aircraft manufacturers and technology suppliers. And among the European suppliers, we have been able to cooperate and compete. And even more important: Europe has a clear idea of the global nature of this industry, and has the skills to jointly work with other continents, to harmonize standards and to achieve global interoperability.

Now, I would like to bring up some specific points to substantiate this statement. Indra, the Spanish IT leading company, is present in many aeronautics and air transport segments, but, today, I will refer to the domain of Air Traffic Management and Airports technology where Indra is a playing a leading role among the ground industry manufacturers.

2. The Example of Indra

Today, European ground manufacturers are able to compete in international contestable markets with a remarkable degree of success. Indra is a good example of it, having been awarded in 2010 Year with a good number of relevant contracts in other continents, namely Surveillance Radars and Area Control Centres in China, Tower of Control systems and Radars in India, Nation-wide ATM programmes in Perú, Omán, Morocco and Kuwait among many others. All of this shows that today European companies are well placed in this domain, but this position could be deteriorate or even vanished if we all do not strive to stay ahead of the game.

3. For Achieving the Goals of SESAR

In Europe, ATM ground systems R&D and innovation are mainly driven by our main ANSP customers and by the SESAR Programme, the technology pillar of the Single European Sky. So, we all agree on that achieving the goals of SESAR are a necessary step towards the new 2050 Vision in terms of economics, environment, safety and capacity.

In order to meet those targets and foster innovation, we can build upon and reinforce the following elements:

1. Cooperation between ANSPs and ground technology suppliers.
2. Collaboration between ANSPs in major developments.
3. Partnership between the public sector and the industry.

The cooperation between ANSPs and technology suppliers is a pre-requisite for innovation. The new technology aims to support the evolution of the modes of operation of the airspace users and air navigation services providers. Therefore, it is imperative that there is an intense dialog between the technology supplier and air navigation service provider in order to test and evaluate and validate the new concepts in near-operational environments.

A good example of collaboration under this scheme is the ongoing agreement among the ANSPs of Spain, Germany, the UK and The Netherlands for using a common 4 Dimensions Trajectory Based Flight Plan Data Processing System, among other crucial components of ATM Automation, constituting the so called iTEC (interoperability Through European Collaboration) Programme. This example is today the most firm pillar for the success of the future Single European Sky derived from the outcomes of SESAR.

We can say that sharing the same technology is the foundation on which is based this firm agreement. Another key is that iTEC is not a “Lab Prototype”, on the contrary, it will be integrated on some of the most mature and advanced ATM systems of Europe, as are the SACTA of AENA (Spain), and the iCAS of DFS (Germany). Those systems,

along with the future NATS-iTEC of UK, the future LVNL iTEC and others that will joint in the future will constitute the backbone of the future European Interoperability.

In my view, the success of the above has been a consequence of the shared commitment of the ANSP and the suppliers to the project. This is the type of collaboration that shall occur at a European level.

Finally, in the area of Public Private Partnerships, the SESAR Joint Undertaking has brought into a single program the founding members (the European Union and Eurocontrol), 16 industry members, and a similar number of associate members. The R&D foreseen by the European ATM master plan is now put into a single and shared program. The program is highly complex given the ambitious level of changes envisioned and the number of actors involved. It has not been easy venture to ramp-up but we are arriving at a cruising speed with the sight of the first deliveries occurring this year.

SESAR's challenge now is to move into industrialization and Deployment. And the key for its success will centre around resolving an appropriate funding and governance scheme. Moving R&D into innovation and new systems into operation is what brings real benefits to airspace users and to society. And at an international level, this European showcase enhances the competitiveness of European manufacturers in the global markets.

4. Closing Remarks

I would like to close my intervention by restating the commitment of Indra to the EU programs and in SESAR in particular. The new Vision 2050 can become a reality with the European Union's commitment to the outcome of the Deployment of SESAR and to the future of R&D beyond the current program. This goes without saying, the support is also essential for the competitiveness of the European industry, the bringing together of diverse actors to work together.

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-45

Preparing the Future of Aviation – Three Thoughts

Jean-Paul HERTEMAN
Chief Executive Officer& Chairman of the Executive Board – SAFRAN Group
Member of the High-Level Group on Aviation Research

Abstract. Three thoughts. First: 2050 is far but we need a vision for this horizon. Second: Europe will not reach its public policy goals – prosperity, environment, safety, job, etc. – without a strong European aviation industry to deliver the means. Third: the rise of the aeronautics related RTD at the European level must be sustained in the coming years and even be increased. It is more than important to continue the RTD effort in the FP8 dedicated to Aeronautics and Air Transport. Public and private funding should be blended within the Framework Programme.

Keywords. Private industrial investment, European policy making

Three thoughts I would like to share with you this morning.

1. The First One Is: 2050 Is Far but We Need a Vision for this Horizon

Forty years ago, in the early 1970s, our predecessors had a vision and an ambition which has shaped the European Aeronautics and Air Transport sector as we know it today.

Remarkably, this vision acknowledged that Europe was the right scale for such an effort.

On the political side, the European institutions of the time realized that a mobilization of resources in the field of science and technology at the European level was necessary to support a renaissance of Europe in Aeronautics and Air Transport. The first cooperative Cost, then BriteEuram programmes were launched. I remember that well. I was a young research engineer in materials, trying to participate in these.

This policy was pursued over the years and European cooperation has more recently been deepened with the strategic research agenda by ACARE and the launch of instruments such as Cleansky.

The results, as we can witness them here in these Aerodays, are outstanding after forty years, Aeronautics and Air Transport are major contributors to the prosperity of the people of Europe.

Commissioner Geoghegan-Quinn, I want to commend you and your colleague Commissioner Kallas for the launch of the initiative: “beyond Vision 2020, towards 2050”.

It should be clear to everybody that forty years from now, in 2050, the world of aeronautics and air transport will be a truly multipolar world with the emergence of new major players. It is as well crystal clear that the place of Europe in the world will

be defined by the vision and the ambition that we will dare to have today in the field of Aviation and Space and by our ability to carry them into reality.

And it starts now.

2. Second Thought

The European Commission has stated its ambition for an innovation policy and for an industrial policy. Well, when on the European scene a French engineer pronounces the words "industrial policy", it may lead to some difficulties and misunderstanding. Let me thus express here my vision of the relationship we expect between the industry and the policymakers.

Europe will not reach its public policy goals – prosperity, environment, safety, jobs… – without a strong European aviation industry to deliver the means. The European aviation industry is one of the few levers that Europe owns to make globalization more an opportunity than a threat for the European citizens. I would think it is coming from nothing else than the (discriminating) ability to innovate we have been able to build so far.

As you know, your industry operates in an extremely regulated environment. These public regulations, be they about flight safety, environment protection and many other topics, are necessary and welcome and do structure the innovation in our sector.

Moreover, aerospace has no choice but to invest today in innovations which will meet their market in twenty years from now or even more. In such a long term marketplace, we need a common public-private understanding of the long term targets and, to some extent, of the ways to achieve them.

Commissioner, let me show you this: an engine turbine blade made of carbon ceramic material. It is four time lighter than the metal equivalent part and withstands temperatures higher than the melting point of the special turbine metal alloys. This technology effort was started in the 80's and will reach the market around 2020. It will bring about 3% reduction in fuel burn.

The "vision 2050" provides that: a coherent framework for both our private investment decisions and your policy making.

This is the fundamental reason for blending public and private funding within the framework program: we two are partners to create our common future.

3. The Rise of the Aeronautics Related R&T at the European Level Must Be Sustained in the Coming Years. In Fact, It Should Even Be Increased

Why?

Because we now have to face the exceptional challenges of both climate change, limitation of energy resources (shaky outlook for the unclear energy).

Remember: during the last 40 years, air transport has grown twice faster than the GDP.

The growth is far from being over, in emerging countries first, but as well in developed countries and Europe.

It has been made possible despite a structural rise in oil price because aerospace technologies allowed cutting the fuel burn by 70% per seat per mile.

To continue growing at this rate, we need to deliver the same level of improvement in CO_2 footprint by the next decades. I believe that is doable but it is a challenge that

requires the mobilization of the best of the best in the scientific world as well as in the industry world.

At this level, it is truly a society challenge and it must be managed as such. And it is a global challenge. We will need major breakthroughs in aeronautics to do it. And major breakthroughs in air traffic control to make it possible.

The increase of the FP7 budget versus FP6 and FP5 – 300 M Euros per annum versus 190 M – has shown to be an efficient instrument to boost European investment in aeronautics R&T.

It is more than important to continue this effort through a budget in FP8 dedicated to Aeronautics and Air Transport and indeed increased to a global level that will match the unique challenges we face. Be sure our industry is fully keen to invest its share of the effort.

Not an easy decision to make by the time being for sure but I do believe it would be one of the best investments Europe can make today to build the future.

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-48

The Future of Aeronautics, a European Perspective

Charles CHAMPION
Executive Vice President, Head of Engineering Airbus

Abstract. The author gives in this paper some thoughts on how to respond to the future travelling public expectations, viz to fly in greener aircraft with access to their digital world in flight with the best level of quality and comfort. Airbus is ready to take on these challenges but the question is: "will the EU be alongside Airbus in the endeavour?" Various examples of Airbus innovations are presented: fly-by-wire A320, double-deck A380, brake-to-vacate technology, ALCAS (Advanced Low Cost Aircraft Structures), 'MAAXIMUS' project for novel and cost effective composite structures, active participation in Clean Sky, leadership of the Smart Fixed Wing Aircraft (SFWA) technology demonstrator, etc. Airbus has proposed a concept plane to help crystallise its modern ideas and shape them in a communicable form. Innovation has become the major competitive differentiator.

Keywords. Airbus, fly-by-wire, Brake-to-Vacate, ALCAS, aircraft-pod-concept

Good morning ladies and gentlemen, I am very pleased to have the opportunity to address you today. As I am the middle Airbus speaker this week, delivering the middle speech of the day on the occasion of the middle day of the conference, I will now ensure that my address to you is not "middle of the road"!

As you know, I have been asked to speak to you today on the subject of "The Future of Aeronautics: A European Perspective".

But how can I fit the future of aeronautics into the next 15 to 20 minutes? The subject is too big, the potentials are huge, and the impact on society could be so significant. Should I start with the product, the aircraft itself, or with the constituent technologies? Perhaps this would be a natural start point for someone trained in aerodynamics, Or with the wider aviation system, including those aspects which the flying public directly encounter, such as security. I will give some thoughts on all, and from a European perspective, I hope not just an Airbus one.

Before going into the technology perspective, it is important however to remind you that Airbus' CEO Tom Enders spoke to you yesterday about our perspective of the future, the importance of policy makers understanding the importance of unlocking and accelerating the technology. He explained that this was against the context of recent research Airbus commissioned amongst 10,000 people around the world. I would like to provide you with some more information on our findings.

The findings from the opinion survey we did with the travelling public showed very clearly that they are expecting to fly more in the future so European's aviation sector must meet growing passenger demand. Their demand is not only in terms of volume but also in terms of expectation. People expect to fly in greener aircraft with access to their digital world in flight with the best levels of quality and comfort. From an engineer's perspective, this may sound like an unrealistic consumer "ask" but what we

Figure 1. Airbus A380.

Figure 2. Airbus A320 NEO.

Figure 3. Advanced Low Cost Aircraft Structures.

at Airbus need to emphasise to you is that we are ready to take on these challenges but the question back to the rest of you is – "will you be alongside us in the endeavour"?

Airbus reached a milestone last year in that we reached our 40 years since foundation. Our success was built on our ability to bring innovative products to the marketplace. Headline examples include, the fly-by-wire A320 and the double-deck aircraft, the A380, an aircraft I personally know very well! You will forgive me if I take this opportunity to point out to you that 10 million passengers have flown on this aircraft, our airline customers are giving us great feedback on the performance and very positive passenger feedback their A380s are providing them.

There are also other more recent examples of Airbus innovation such as the "Brake-to-Vacate" technology which has provided a means to reduce the runway occupation required per plane at airports. We can be proud of our achievements.

But these are examples underpinned by very many smaller, largely uncelebrated product innovations, which are continually improving the value of products we offer to the marketplace. Innovations based on the continuous efforts we perform on Research and Technology, some of which are presented at this conference in Madrid.

You will also see some photographs on the screen of some of the projects. For example, the ALCAS project (Advanced Low Cost Aircraft Structures) Technologies

Figure 4. Airbus A350XWB Wing.

used extensively in the automotive industry were adapted to Airbus' own wing assembly requirements.

Partly due to the experience from this project, and for the first time in Airbus, the A350XWB wings in the new North Factory at Broughton are being built in a horizontal rather than a vertical jig. This new methodology not only saves space and other manufacturing innovation but is an important human factor innovation too – due to the ergonomic benefits the new jig layout brings attitude. Ultimately, the ALCAS demonstrator helped to understand the new manufacturing processes and validate the design by structural tests.

And to continue, the MAAXIMUS (More Affordable Aircraft through Extended, Integrated and Mature Numerical Sizing) project in which 57 partners from 18 countries collaborate in development of novel and cost effective composite structures, which extends the capability of industry to further exploit this material technology.

And last but not least I should mention the TANGO (Technology Application to the Near Term Business Goals and Objectives of the Aerospace Industry) project, partly funded by the European Commission, which generated a number of innovations. Some of the most noteworthy contributed to the A380 and ultimately to the A350, like the composite centre wing-box and some fuselage sections and shells that were also manufactured in Carbon Fibre Reinforced Plastic. The results from this research project were a fundamental basis for some of the Airbus' "first time to market" innovations, like the first CFRP fuselage section in a large, commercial aircraft (i.e. Section 19 in the A380).

Of course there is a strong tradition in Spain on the subject of composite materials, as you will appreciate from the visit schedule prepared as part of the Aerodays conference. At Airbus the most recent product innovations have benefitted from this capability. The A350 already contains 53% composite materials in fuselage and wing which results in 60% lower fatigue and corrosion maintenance. It also provides a 25% reduction in fuel burn & seat mile cost. This results in major Environmental benefits through advanced technology like the lowest CO_2 emissions and NOx emissions up to 35% below CAEP6.

Figure 5. Fuselage section.

Figure 6. Airbus A350.

All of this was possible through Innovations based on the continuous efforts we perform on Research and Technology. And those efforts must continue, and indeed accelerate, to meet the challenging demands faced by the aeronautics sector. The Clean Sky programme sets a strong focus on tangible results and demonstrators will therefore be needed to evaluate new technology to be ready in order for us all to fulfil Vision 2050.

It is the most ambitious European Aeronautic research project ever undertaken. Actually it is a Joint Undertaking (JU) between the European Commission, research establishments and the industry, setting out for the greening of aviation.

To achieve the highly ambitious ACARE goals by 2020, by now over 400 Companies have started their contribution. Airbus is steering the Smart Fixed Wing Aircraft

(SFWA) Technology demonstrator activities and we are convinced that this is an efficient way of doing Research at European level that needs to be continued in future.

And we are sure that we can even do better in the future. What is important to get there is to prepare on time. We have to start now with a clear vision where we want to be.

The Vision 2050 presents our aspirations for the future: We hope that the European Aviation Community will continue in leading the world in sustainable aviation products and services whilst meeting the needs for EU citizens and society. To do so we must innovate at Airbus and the Industry at large will need to address competitive challenges from what were know as the emerging economies but could be more adequately called the booming economies. I refer to the BRIC countries. We cannot hope to compete with them on price; innovation has become the major competitive differentiator.

In fact, Aeronautics and Air Transport are already ensuring safe and sustainable mobility for passengers and freight, generating wealth and economic growth while contributing to the balance of trade and European competitiveness. We are providing highly skilled jobs, here, at home, which is key to our success. Once again, in 2050 we will still be doing this, but we hope, even better.

To illustrate my point, I would like to show you more concretely how Airbus efforts can help meet Societal and Market needs, for the overall benefit of the EU citizens, and world passengers.

New materials and processes developed through research and technology projects underpin the Vision 2050 goals of "Maintaining and extending industrial leadership" and "Prioritising research, testing capabilities and education". These will be exploited in the next generations of aircraft and help to secure step changes in efficiency, which in turn supports the goal of "Protecting the environment and the energy supply". All of these technologies build upon each other to shape the future for our industry and our society.

Airbus has proposed a concept plane to help crystallise these many and various ideas, and shape them in a communicable form.

Let's look at what may be round the corner – although there are some may agree with Albert Einstein who said:

> "I never think of the future … it comes soon enough".

The airports of the future will have to be much more practical than today for the passengers too! Taking a plane could be as simple as taking the Metro, with planes parking alongside a loading bay on which passengers are waiting, similar to a station.

Alternatively passengers could be calmly pre-seated in modules (or capsule compartments) before the plane actually arrives. These compartments would be loaded onto the plane as it lands.

Airbus engineers describe this as the 'Aircraft Pod Concept' which blurs the distinction between aircraft and airport; after all they are all part of an ensemble that transports people and goods.

Moving back to the present though, I know that the subject of bio-fuels is another topic being discussed at this conference and Airbus were delighted to sign a contract on this yesterday.

But the key to all these fuels is the efficiency of the engine and the engine and aircraft combination after all; waste is still waste whatever form it takes.

We are obviously looking at various options with the main propulsion providers to define an innovative power plant. In the near term this might mean Open Rotors, Ad-

Figure 7. Airbus Concept Plane.

vanced Turbofans, Geared Turbo Fan or even Ducted Counter-rotating Fans but in the long term perhaps we might see Liquid Hydrogen thrusters or even some new, as yet unknown, propulsion techniques.

Many, if not all, of these technologies will require significantly new and improved materials.

Some materials of the future will include additional functionality that provides transparency on command, negating the need for windows.

New materials could be self-cleaning and even self-repairing. Think of the leaves of a lotus plant, which water rolls off in beads, taking contaminants with it. Today this is already used on the surfaces of cabin bathrooms. In the future this will be found on the fabric of seats and the carpets on which we walk. Self-repair of this kind is already used today in surface protection. Certain paints can seal a scratch just as the human skin heals itself when scratched.

Materials that change shape and return to their initial shape, like the organs of living creatures, are a very real possibility. Such materials might be metals that have a ‘memory’; or are covered with a ‘skin’ of material that carries a system that will instigate a shape change. A memory is created by providing materials with a certain level of intelligence. This means the ability to ‘control’, so a sensor system and an activator system exist within the material.

The future passenger cabin will of course be ecological. No more non-renewable materials like metal and plastic, but plant fibres, fully recyclable, that can be grown to the desired shape from responsible, sustainable resources.

Airbus is committed to researching sustainable materials and how to dispose of them at the end of their life and this is why we are one of the partners in the PAMELA programme (Process for Advanced Management of End of Life of Aircraft).

At Airbus we have looked at a multitude of visions: the Supersonic Plane, the Hypersonic Plane the Cryoplane and the Cruise Ship of the Sky, to mention but a few. But Airbus’ experts in aircraft materials, aerodynamics, cabins and engines have also come up with a design to meet the expectations of the passengers of the future.

More than a flight of pure fantasy, The Airbus Concept Plane illustrates what air transport could look like in 2050 – even 2030 if advancements in existing technologies continue apace. Ultra-slim wings for lower aerodynamic drag, semi-embedded engines which significantly reduce noise pollution and increase lift, a completely reworked tail design and a fuselage shaped to optimise lift – these are externally visible signs of what our engineers have dreamed up. This Concept plane is not our next generation aircraft or even the generation after that, but rather a playground for future-oriented ideas. We are inviting researchers and interested parties around the world to talk to us because we want to be the ones who turn these visions of the future into INNOVATION, – meaning into a "flying reality" – before our many competitors.

I have the privilege to lead the thirteen thousand engineers at Airbus and through them many thousands more in our partner organisations. They are motivated by a huge pride in our products, and an excitement about flight. Yes, there are many professional and technical challenges which provide for a satisfying career – but it is the dream of flight that provides the first motivation. This is alive and well at Airbus – despite the fact that flight is now routine, almost mundane, for many citizens of Europe – this spirit of excitement and improvement is needed to take us to the future of aeronautics. Airbus will play its part in defining this future together with all the industrial partners and industry stakeholders.

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-55

Tackling the Environmental Challenges to Aeronautics

Eric DAUTRIAT
Executive Director – Clean Sky Joint Technology Initiative

Abstract. The environmental challenge has become over the last ten years more and more the main driver for future technologies and future aircraft architectures. The paper deals with the following topics: from local to global – anticipating the oil peak, another political and societal challenge – ACARE and environment – Clean Sky, a game-changing Public-Private Partnership – the numerous technical areas speeded up by the environmental challenge – Primes, Tiers One, Research Organisations, Universities, SMEs, are the Clean Sky Partners – the full set of demonstrators involving Clean sky Members and many Partners – Clean Sky will deliver main demonstrators from 2014 – the variety of means – Game-changing concepts will tackle further environmental challenges.

Keywords. Environment, demonstrators, Clean Sky partners, game-changing concepts

The environmental challenge is not the first challenge that the aviation sector is facing. But as Antonio Vasquez, the Iberia CEO, said yesterday, it is maybe the biggest ever. It is now strongly contributing to a change of mindset. Over the last 10 years, it has become more and more the main driver for future technologies and future aircraft architectures.

It has been decades since aviation started to pay a lot of attention to environmental parameters. Here I refer to noise and air quality, where a very impressive progress was made. This concerned the local effects of aviation. It was prompted by the residents' claims, in the vicinity of airports. It had significant effects on aircraft design, in particular on the engine design.

But what we are facing now is of a different scale, which comes on top of these local effects. This is about climate change, as everybody knows. It is now about the planet: even with a limited impact, aviation is interacting with the planet and mankind. Two eminent interlocutors and a great political challenge! The image of aviation in the eyes of all citizens is at stake, and we have to better explain our action to them.

Like the climate change, the aviation sector is also global, worldwide, and thinks global: this allows to have a common, efficient approach.

Another major characteristic of the greenhouse effect is that it is long-term and cumulative. Aeronautics is long-term as well. This is probably the industrial sector where the products have the longest research and development lead times and the longest operational lifetime: there are more than 50 years from the concept of a new part to its disposal. The replacement cycle of commercial products is slow. This is an apparent paradox when you consider the very hightech features of this sector, at the leading edge of progress. But what is for sure is that the lead times of human action on climate and

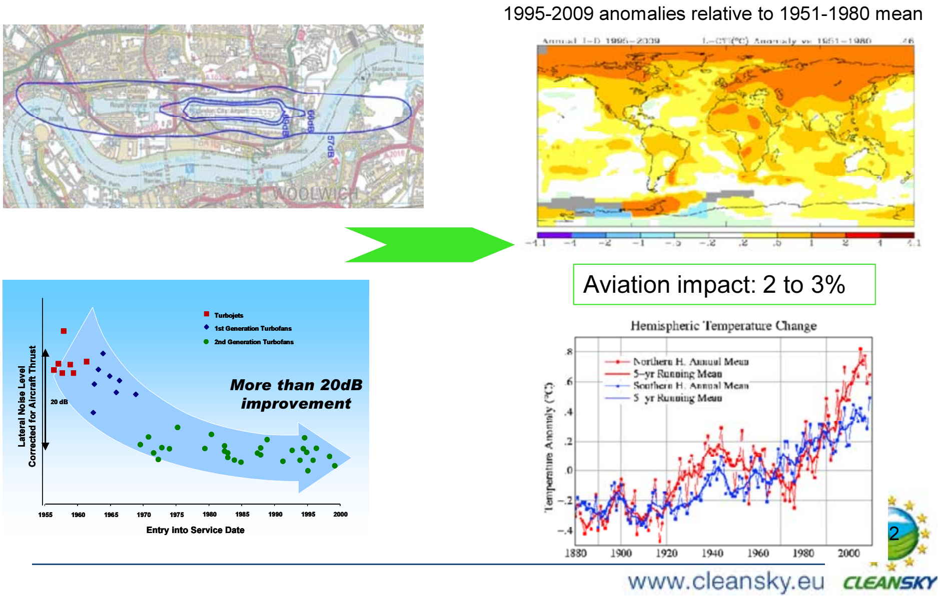


Figure 1. From local to global.

Figure 2. Anticipating oil peak.

on aeronautics investments and vision are commensurate: this helps to define a clever strategy and to keep to it.

This does not mean that we can linger on our way to greening aviation: for sure, acting quickly is even one of the reasons why public sector support is needed.

I'm not certain, even if I do hope so, that climate change will remain at any time as high on the political agenda as it used to be in recent years. The lukewarm results of the Copenhague summit still resonate. This makes the vision and leadership of the European Union on this matter all the more necessary. But what is for sure is that the energy challenge will continue to grow. This is another long-term matter. Reducing the fuel consumption is a must, not only economical, but, I would say more deeply and even more urgently, important in societal and political sense. Biofuels will not do the job

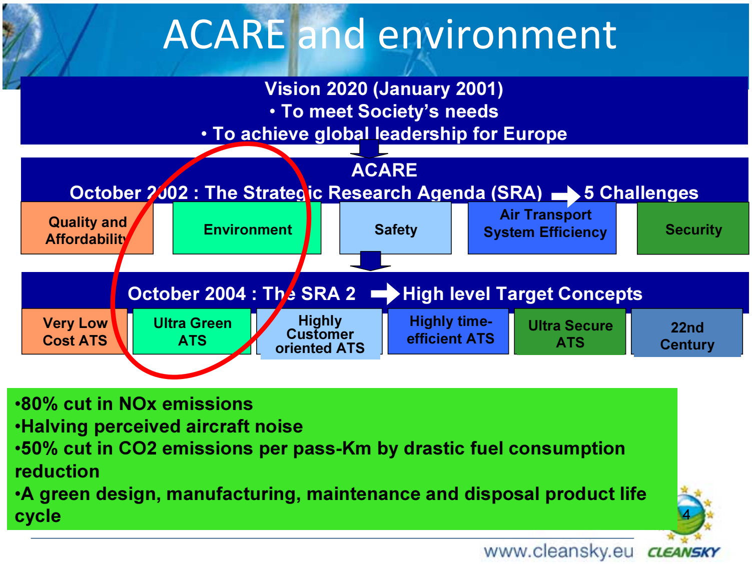


Figure 3. ACARE and environment.

alone. Designing even more abstemious aircraft, with the oil peak approaching, is a challenge which duplicates and reinforces the CO_2 one: the good news is that the aeronautical industry has always made successful efforts in this direction, as it did for noise. In the last forty years, this fuel consumption has decreased by 70%. Of course, along the way it becomes more and more challenging and costly to improve, and this leads to finding more efficient and comprehensive ways to organize and fund research.

As a consequence of these global and long-term features, the aeronautical sector is probably the best organized, not only at European level, but also beyond. The ambitious targets set by ICAO and the upcoming definition of a standard for CO_2 could not have been set if the aviation sector had been scattered, if the industry itself had not initiated the right steps.

You all know this slide, but you would miss it if I didn't show it. The technological platform ACARE, of which our moderator today is an outstanding co-chairman, has brought together the whole sector – public and private players – in an active research and innovation global reflection, committing to ambitious, shared targets.

Long term, global, well organized, and high tech: this is why and how aviation can bring a lot to tackling the environmental challenge that mankind is facing.

In return, this environmental challenge is really helping to structure and focus aeronautical research.

The ACARE target of halving CO_2 emissions with technologies available in 2020 cannot be reached only by the market invisible hand. It needs a long-term public and private common vision and commitment, it needs stability, while being in step with market needs: CO_2 reduction cannot just trail behind the market with a kind of loose reaction loop, it needs a more voluntarist approach, adding some technology-push to the pure market-drive: this is about following a policy and long-term objectives.

This is what Europe, in particular the European Commission, impulsed with the Clean Sky Joint Technology Initiative, a programme started in 2008, reaching now its steady-state level, aiming at providing system-level demonstrators of green technolo-

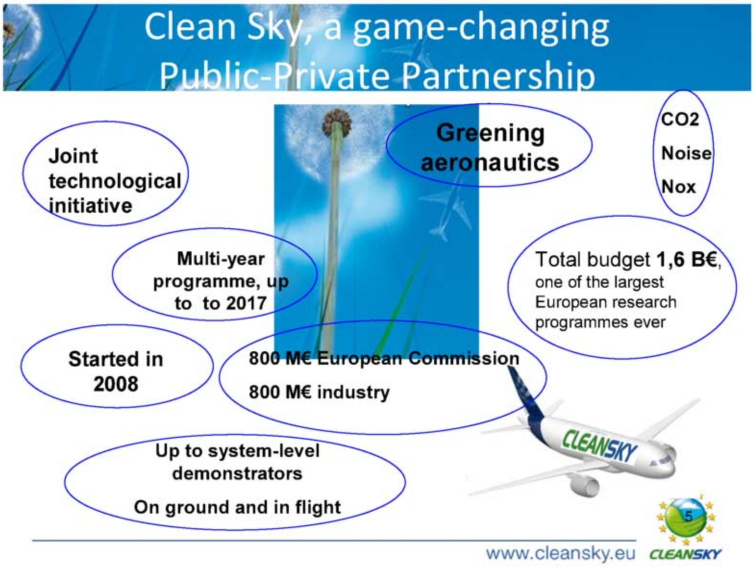


Figure 4. Clean Sky, a game-changing Public-Private Partnership.

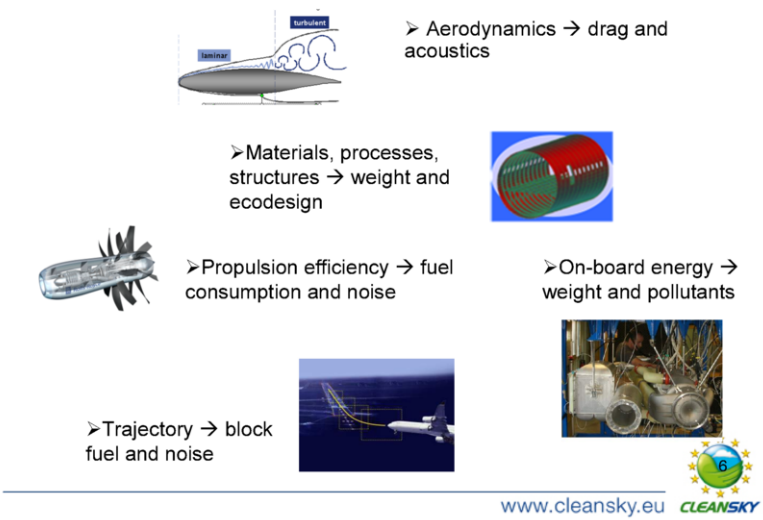


Figure 5. Technical areas.

gies for all kinds of aircraft, with 2017 as a time limit, with clear CO_2 and noise reduction targets. Clean Sky is, by far, the largest research programme of Europe in aeronautics ever.

At the last, Aerodays, five years ago. Clean Sky was still in limbo. The dream of starting such an initiative was taking shape. Then, the build-up phase was somewhat difficult. Now we can say that we are well on track – with some quite exciting technical challenges and risks ahead of us!

Figure 6. Clean Sky players.

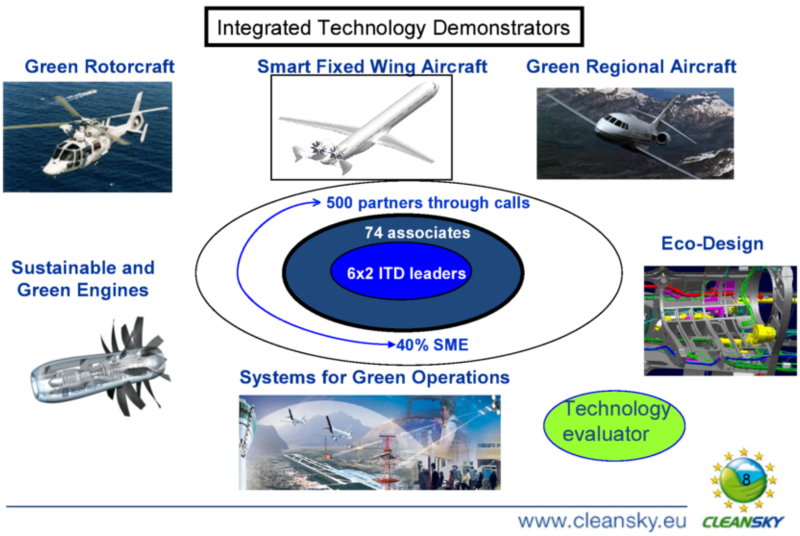


Figure 7. A full set of demonstrators involving Clean Sky Members and numerous.

Sharing such targets, all across the industry, is meaningful. It goes beyond the usual coordination of collaborative projects, because this Initiative is longer term, comprehensive, results-focused, and puts together most of the aeronautical Primes, Tiers One, Research Centres and hundreds of partners to bring research up to innovation. You can see here a random sample of these participants to Clean Sky. These players not only discuss and share policy-level objectives, but work together on a day-to-day basis. Lasting new links are being created between Universities, SMEs, integrators and so on, throughout such a 10 years cooperation.

No other goal than the global warming could have been so widely inspiring, both for the private sector innovation capability, and for the public sector policy.

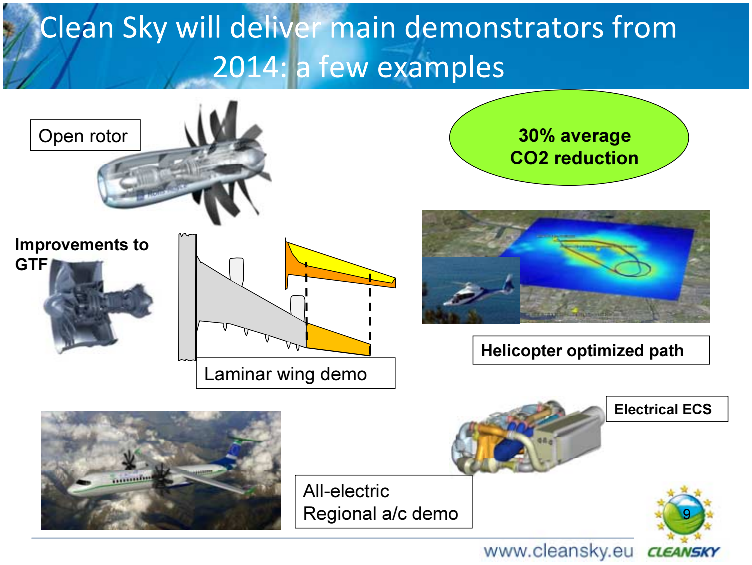


Figure 8. Clean Sky will deliver main demonstrators from 2014: a few examples.

Six different areas are addressed, each of them involving several large, ground or flight demonstrators at a high Technology Readiness Level: Large aircraft. Regional aircraft, Rotorcraft, and with a transverse role, the Engines, the Systems and the Ecological Design.

Through the interfaces between these areas, I am convinced that a more holistic approach for research is taking shape. This is the first time that such a set of common objectives is agreed by all stakeholders, translated into the different aircraft types, addressed through a common and stable programme, with cross-links and common rules, evaluated and monitored through dedicated tools.

Because these teams are building integrated demonstration products, and because the JTI reflects the structure of the aeronautical sector, these areas are managed by 12 major players of the European industry. Around them, they involve also a lot of associate members. The coordination and management are ensured by a Joint Undertaking, reporting to a Governing Board where strategic decisions are taken, from the industry, the research organizations and the European Commission. This Governing Board is chaired this year by the previous speaker, Charles Champion – and vice-chaired by Rolf Henke from DLR.

But the Joint Undertaking is also involving more and more partners through calls for proposals every 3 or 4 months, and we have currently, in total, close to 400 stakeholders in Clean Sky – and we keep growing.

The topics of these calls for proposals are fit to SMEs, which currently represent 40% of the winners, including a lot of newcomers in aeronautical research. This shows how much and how widely such a set-up can prompt innovation.

Many technology streams are involved in the CO_2 noise reduction, from materials to aerodynamics to propulsion. The large demonstrators are involving for instance:

- The Open Rotor, on ground and in flight – one of the most promising and also, one of the most demanding, game-changing concepts in Clean Sky;

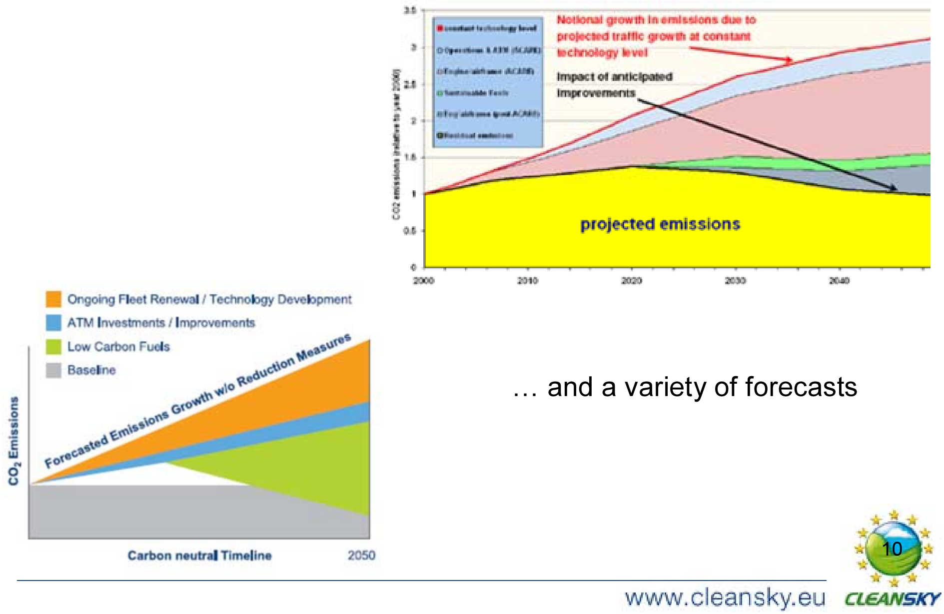


Figure 9. A variety of means.

- A natural laminar wing flight test;
- An all-electric (or as "more electric" as possible!) regional aircraft fly test, involving also new structures and health monitoring, to mention just a few of them. They will be tested mostly by 2014–2015, but first intermediate results and deliveries are being produced now: this was highlighted in the two Clean Sky sessions this morning.

The average CO_2 reduction target, depending on the aircraft type, and depending of course on the success of the demonstrators, is in the range of 30% – while the noise reduction targets are in the range of 10 dB. This shows the strong contribution from Clean Sky to the ACARE goals. Other technologies, stemming from other funding sources, for instance national, may or must be involved, because Clean Sky is building synergies and acting as a catalyst.

Besides CO_2 and noise reduction, Clean Sky has also a focus on Eco-Design, the aim of which is to reduce the overall environmental footprint throughout the life of the product. I'm pretty sure that the attention paid to this matter will keep growing, to avoid waste, chemicals and allow for full recycling.

What we are providing with Clean Sky is demonstrated technologies. They will be available for further development. It is only through there inclusion in operational aircraft that the relevant CO_2 and noise reduction will materialize.

In parallel, let me remind you that, in the field of ATM, through the European Single Sky and SESAR, CO_2 improvements in the range of 10% are expected. Both activities, aircraft technologies and ATM, are complementary and coordinated.

As Clean Sky is far from being the end of the story, it is needed and feasible to go beyond, well beyond, what is currently being addressed. As we have seen yesterday, the flightpath to 2050 is setting new targets: 75% of CO_2 reduction, 65% of noise re-

Figure 10. Game-changing concepts will tackle further environmental challenges.

duction and so on. We are rather at the beginning, of what this environmental mindset may or will trigger. For this, a variety of means must be used.

Biofuels are not addressed by Clean Sky. In the future, there is no doubt that they will strongly emerge and contribute to reach our ambitious targets, to an extent which has still to be better defined as you can see on this slide... But most of the technical and industrial challenges of the biofuels are upstream, in the production and distribution area, more than in their use by aircraft, and they are not aviation-specific.

The aircraft technologies themselves have still a significant potential for innovation, to further green our aviation. We will be imaginative and ambitious. We are able to fly brand new architectures and concepts. More game-changing architectures, whatever they look like at the end, are still ahead of us. A still closer cooperation between all players, and a still wider holistic approach, are needed.

I focused on CO_2 but there are other potential sources of radiative effects. In particular, scientists have also to understand and better model some effects on the global warming from phenomena such as “contrails”, the avoidance of which could prompt changes in the flight altitudes and routes.

The emission trading scheme, which should, as such, significantly contribute to change the game, should also be used to bring still more support to research and innovation in the field of environment.

The Joint Technological Initiative concept, which had itself to be demonstrated, exists now; lessons can be learnt from the current Clean Sky for future improvements, and this JTI concept is fit for purpose to tackle future challenges, in the context of the Innovation Union.

Working for future of the planet in such a high-tech sector has the ability to renew the passion with which we can reach the Moon. By the way, reaching the Moon is carbon-free, even with a rocket (maybe not contrail-free, this has to be checked!), but this is another story, maybe for some European Space Days somewhere...

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-63

Flightpath 2050: Europe's Vision for Aeronautics

Axel KREIN[a] and Gareth WILLIAMS[b]
[a] *Senior Vice-President, Research & Technology – Airbus SAS*
[b] *Vice-President, Business Development – Airbus SAS*

Abstract. Towards the end of 2010 Vice-President Kallas and Commissioner Geoghegan-Quinn invited a group of European top-level representatives of the European aviation[1] industry to develop a new vision for European aviation with a 2050 horizon. The aeronautics part of this vision encompasses all matters relating to the air vehicle, comprising the vehicle and its systems, its technology, design and manufacture as well as its maintenance, repair and overhaul.

Keywords. Environment, energy, safety, security, competitiveness, Flightpath 2050

1. A Vision for Aviation

Aeronautics is at the heart of the Air Transport System. Over the past 40 years, the European aeronautic industry has successfully risen from a niche sector to a world leading industry. During this time the demand for air travel has grown very significantly and Europe has taken an increasing share of this market. European Aeronautics Industry numbers approximately 82,000 aeronautical companies [1], including a significant share of small and medium-sized enterprises which in 2009 supported 468,300 sustainable and highly skilled jobs. In the same year, aeronautics generated a turnover in excess of €100 billion, of which approximately 60% is exported outside the European Union (Fig. 1).

On average, 12% of aeronautic revenues, representing almost €7 billion per year for civil aeronautics alone, are reinvested in Research and Development (R&D). Every Euro invested in aeronautics R&D creates an equivalent additional value in the economy every year thereafter. Aeronautical technologies are catalysts for innovation and spill-over into other economic and technological sectors, thus contributing to the growth of the European economy as a whole. Around 20% of aerospace employees work on R&D. This has been achieved through the collective efforts of major companies, thousands of small and medium enterprises (SMEs), academia and research laboratories. The role of the European prime platform integrators in guiding and setting framework for these efforts has been vital. Key to this success has been the constant hunger to innovate and to exploit technology where it benefits the customer. That is both the airlines and the travelling public.

Equally important has been the concerted efforts to improve coherence of research and technology programming and funding. As a result of this Aeronautics continues to be the highlight of an integrated high technology research, development and manufacturing sector.

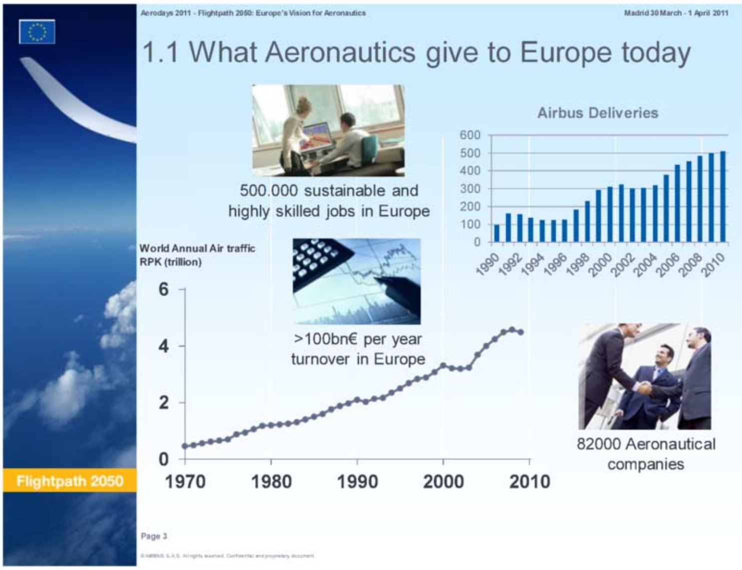


Figure 1. What Aeronautics gives to Europe today.

2. Challenges and Goals for the Future

All these efforts have provided a firm foundation for the future and there is a tremendous opportunity for European aeronautics. Air traffic is predicted to grow at around 4.8% each year. This growth means that nearly 26,000 new aircraft will be required in the next 20 years (Fig. 2).

However, Aeronautics faces a huge challenge in fulfilling its responsibility to society for protection of the environment, and for being safe and secure. Progress is being made in meeting these challenges but sustaining progress becomes increasingly difficult as traffic volumes grow. At the same time the industrial competition is becoming ever fiercer, not only from established or traditional rivals such as the United States of America but now from new and strong challengers, notably Brazil, Canada, China, India and Russia. Authorities in these countries have understood the strategic nature of aviation and support their industries accordingly, enhancing competition at all levels.

The challenges of the next 40 years are greater by far than those we have faced in the last 40. To harvest this opportunity we depend entirely on our ability to innovate! Technological leadership, the root of Europe's current success, will continue to be the major competitive differentiator. Break-through technology will be required to secure future competitive advantage, to properly manage ever-increasing complexity and most notably to master the environmental challenge. Innovation is not a nice to have – it is a fundamental necessity for survival.

So let me know show you some of the key elements the Vision for the future of aeronautics, which covers the themes of:

- Environment and Energy;
- Safety and Security;
- Competitiveness;
- Customer Experience.

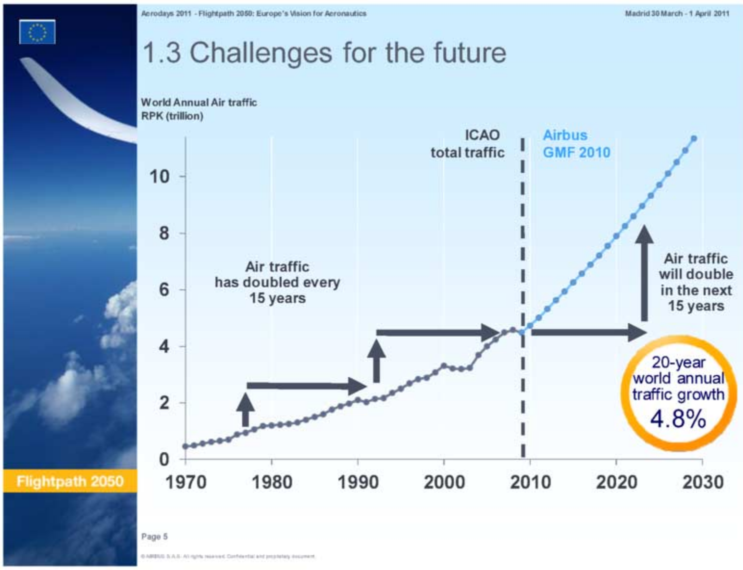


Figure 2. Challenges for the future.

The following sections describe these themes in terms of their potential status in 2050, and what goals must be attained to achieve that status.

3. Environment and Energy

Since the 1960s, Commercial airlines have cut their fuel consumption and, therefore, their CO_2 emissions by 70%. Today, a passenger on board an Airbus A380 only uses 3 litres of fuel per 100 kilometres. However as the effect carbon emissions have on our planet becomes increasingly important, it is essential for the aviation industry to continue to find even more solutions.

So our vision is that in 2050 substantial developments in vehicle and engine have combined and built upon each other to yield a truly new generation of European air vehicles and equipment, with significantly improved and continuously improving fuel and noise efficiency. The air traffic control system is optimised to provide the best trajectories for fuel and time efficiency and associated atmospheric emissions and to address noise. Noise projection on the ground is also reduced. Noise generated by rotorcraft at heliports continues to be in compliance with the local operational rules. Dependence on crude oil is reduced by drop-in liquid fuels from other sources at a competitive cost. Furthermore the effect of aviation on the atmosphere is fully understood. A combination of measures, including technology development, operational procedures and market-based incentives mean that environmental impact of aircraft has been mitigated at a rate outweighing the effects of increasing traffic levels. The public is informed, understands and is convinced that the aviation sector has made the utmost progress in mitigating environmental impacts and therefore considers that air travel is environmentally sustainable (Fig. 3).

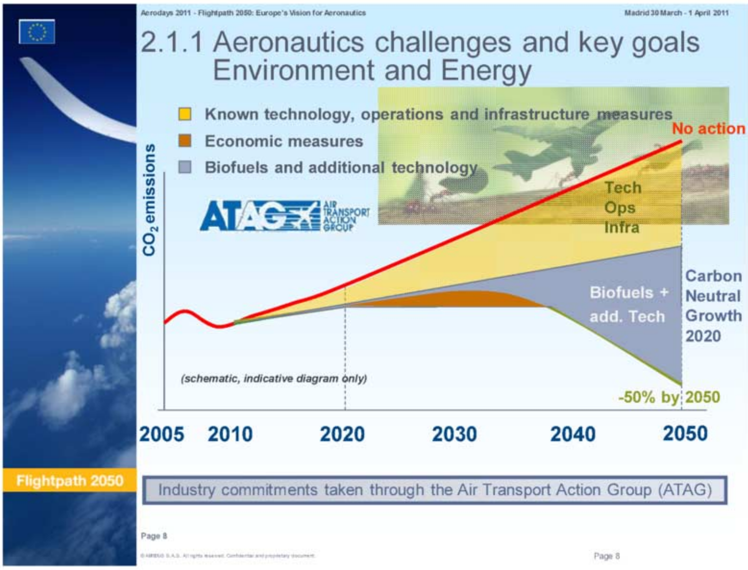


Figure 3. Aeronautics challenges and key goals for environment and energy.

The goals we have set ourselves in order to reach this ambitious state are these:

- In 2050 technologies and procedures available allow a 75% reduction in CO_2 emissions per passenger kilometre to support the ATAG target[2] and a 90% reduction in NO_X emissions. The perceived noise emission of flying aircraft is reduced by 65%. These are relative to the capabilities of typical new aircraft in 2000;
- Aircraft movements are emission-free when taxiing;
- Air vehicles are designed and manufactured to be recyclable;
- Europe is established as a centre of excellence on sustainable alternative fuels, including those for aviation, based on a strong European energy policy;
- Europe is at the forefront of atmospheric research and takes the lead in the formulation of a prioritised environmental action plan and establishment of global environmental standards.

4. Safety and Security

Regarding safety in 2050, European aviation has achieved unprecedented levels of safety and continues to improve. Manned, unmanned, legacy and next generation, autonomous aircraft and all types of rotorcraft operate simultaneously in the same airspace and in most weather conditions. The occurrence and impact of human error is significantly reduced through new designs and training processes and through technologies that support decision-making. Advanced on-board monitoring systems allow the aircraft and air transport system to predict and mitigate technical and operational issues, including weather, before they arise. This state is embodied through the achievement of the following goals:

- Overall, the European air transport system has less than one accident per ten million commercial aircraft flights. For specific operations, such as search and rescue, the aim is to reduce the number of accidents by 80% compared to 2000 taking into account increasing traffic;
- Weather and other hazards from the environment are precisely evaluated and risks are properly mitigated;
- The European air transport system operates seamlessly through fully interoperable and networked systems allowing manned and unmanned air vehicles to safely operate in the same airspace.

5. Competitiveness

In 2050, the innovative, sustainable and highly competitive European aviation industry has cemented its place as the world leader. It is recognised globally for its vehicles, engines, systems and equipment and a large range of very cost effective and energy efficient products. This position has been secured through a seamless European research and innovation system that assures continuity through blue sky research, applied research, development, demonstration and innovation in products and services.

Europe's industry maintains and improves its critical mass, leading edge capabilities and competitiveness through continuous and focused investment funded by strategic industrial and public-private partnerships, supported by cutting edge research organisations and education, organised in geographic clusters and networks. Multidisciplinary design and development tools are used routinely and co-operatively to support a high level of integrated system design. Final product performance is achieved to within a very fine tolerance (0.5%) of design prediction based on balanced design techniques and simulations ensuring right-first-time manufacture. This, with seamless integration of design and manufacturing, and the successful management of complex supply chains, means that development timescales and costs have been dramatically reduced.

Close-to-operations, full-scale technology validation, demonstration and in-flight testing is used to manage risk and to test technology. This enables the relentless pursuit of breakthrough and step-change innovations in products and services. New concepts, methods and tools are used to manage increasing complexity. These features have so enhanced the reputation of European aeronautics that the best researchers, engineers and managers are attracted by the European aviation sector, which has the reputation for being a most highly desirable, attractive, challenging and rewarding career choice.

The goals identified in Flightpath 2050 that must be achieved are:

- The whole European aviation industry is strongly competitive, delivers the best products and services worldwide and has a share of more than 40% of its global market;
- Europe will maintain leading edge design, manufacturing and system integration capabilities and jobs supported by high profile, strategic, flagship projects and programmes that cover the whole innovation process from basic research to full-scale demonstrators;
- Streamlined systems engineering, design, manufacturing, certification and upgrade processes have addressed complexity and significantly decreased development costs, including a 50% reduction in the cost of certification. A leading new generation of standards is created.

6. Customer Experience

The vision for the passenger experience in the air transport system has been presented in other papers at this conference. Aeronautics clearly has a substantial contribution to make in this area. Achieving seamless, secure, rapid and resilient travel that the vision foresees places strong demands on the aircraft and its systems. In particular for that part of the journey that takes place in an air vehicle, air travellers in 2050 expect that their local on-board environment (air quality and temperature control) matches that expected in the home or in the office, and that services and communications for business and leisure is available seamlessly and reliably throughout the entire journey.

The goals identified in Flightpath 2050 include:

- Passengers are able to make informed mobility choices and have affordable access to one another 90% of travellers within Europe are able to complete their journey, door-to-door within 4 hours;
- Flights arrive within 1 minute of the planned arrival time regardless of weather conditions;
- An air traffic management system is in place that handles at least 25 million flights a year;
- A coherent ground infrastructure is developed including: airports, “vertiports” and heliports;
- All passengers pass through security screening without intrusion and unnecessary intervention or disruption.

7. Time Horizons

It is clear that our European vision for aeronautics is extremely ambitious and challenging. Overcoming the challenges and achieving our Vision requires a supreme effort over many years. Aeronautics is marked by the high complexity of its vehicles and systems, all of which are both technology and capital intensive and that are subject to very long development cycles (up to 20 years), they are produced over a time frame of at least 25 years and remain in service for at least another 25 years in which they required product support. We have to consider a total of a seventy year timeframe!

The scale of the risk associated with massive investments in technological research and innovation, which only bear fruit on a long-term basis, is clearly extremely high. Research efforts need to be based on a programmatic approach that provides continuity across R&T efforts over many years. Managing this risk is dependent on the availability of excellent research, testing and validation capabilities and the means to demonstrate integrated solutions at large scale or in flight. It is therefore important to understand the impact of these long cycles on what achieving the vision means in technology terms (Fig. 4).

Because of the large number of aircraft already in service In order to have any real effect on the overall performance of aviation or around 2050 we need to be introducing into service aircraft with many of these innovative features and performance from around 2040. On the basis that more than iteration cycles are needed to bring into the market vehicles individually fully capable achieving all necessary elements of this vision. It will not be possible to reach these goals in the iteration of a single product (Fig. 5).

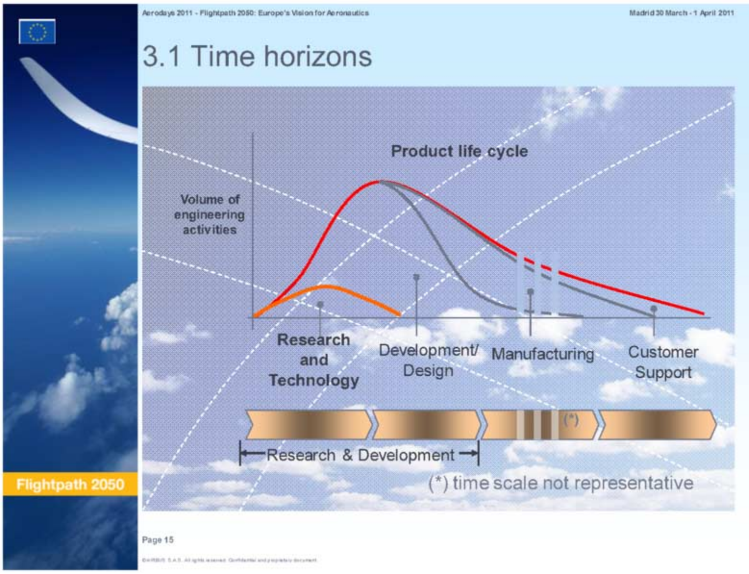


Figure 4. Time Horizons – Product Life Cycle.

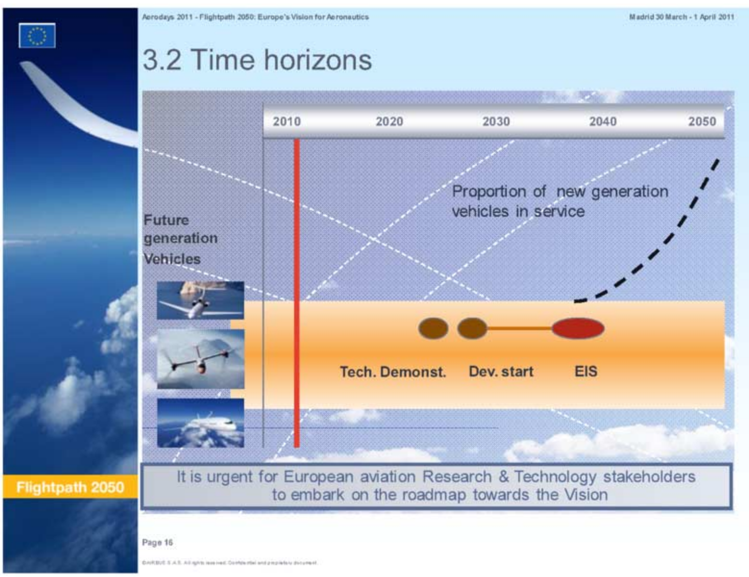


Figure 5. Time Horizons – New Generation Fleet.

So it is clear that the time to embark on the first part of the roadmap towards this new Vision is coming very soon. Indeed it is essential in the planning for FP8!! So how to move from the Vision to action! Today we don't know exactly what is required for us to achieve this Vision. We have a very sound basis of knowledge and understanding but there are also many breakthroughs which are yet to be achieved. There is much more to be learned and to be understood and to be tested and confirmed. We know what is at the end of the journey – but we do not yet have a clear view of how to get

Figure 6. Vision to action.

there! We cannot see all the way towards 2050 today! But clearly we cannot wait. It is imperative to launch actions soon. Before we set off on the journey we need to be sure that we are heading in the right general directions and that we are doing as many of the things that need to be done now, in order to have the right things in place for the steps beyond (Fig. 6).

What is needed is a roadmap from where we are today to the vision. This road map for aviation research, development and innovation, will account for both the evolution of technology and technology breakthroughs and step changes. This road map is needed to guide and support future actions in public and private European R&T programmes towards the Vision including future Framework Programmes. The roadmap must be developed with the participation of stakeholders from all sectors of Air Transport and must be underpinned by appropriate levels of funding.

The leadership of Europe in the field of aviation is underpinned by the work of ACARE in providing the dedicated and independent advice on strategic issues affecting the sector and the preparation of the Strategic Research Agenda in 2001. To continue the pursuit of our Vision for 2050 the primary recommendation of Flightpath 2050 is to revitalise and extend ACARE as the strategic advisory body for research and innovation that encompass both aeronautics and air transport and associated regulatory and institutional enablers. In doing so it should:

- Encourage full participation of representatives of airline, airport and other operational aviation areas;
- Provide policy recommendations to guide the way towards achieving the Vision;
- Bring together authoritative, senior figures from all aeronautics and air transport stakeholders, Member States and the European Commission to build consensus in favour of strategic actions;

- Create the appropriate mechanisms to connect to the equivalent platforms of other transport sectors (where they exist) in order to secure the intermodal objectives of the Vision;
- Launch actions to urgently develop the new strategic roadmap.

Flightpath 2050 was created by the synchronised efforts of many stakeholders in the field of aviation. The Strategic Research Agenda required to secure the vision must now be developed and delivered by the same broad range of stakeholders in Air Transport and aeronautics.

Endnotes

[1] Aviation is used to mean Aeronautics and Air Transport.

[2] Carbon-neutral growth starting 2020 and a 50% overall CO_2 emission reduction by 2050.

References

[1] ASD Facts and figures, 2009.

This page intentionally left blank

Introduction to Part Two
Aviation Technologies and Operations

The second part of the book addresses the technology and operation aspects. After an introductory article about the Clean Sky Joint Technology Initiative, the key technologies responding to the main challenges identified by Europe's Strategic Research Agenda for Aeronautics are addressed in six chapters. Mainly the achievements of joint technology projects of EU level are presented (in brackets the number of papers).

Chapter "*Greening the Air Transport*"

- Flight Physics (5);
- Climate and Alternative Fuels for Aviation (3);
- Noise Reduction (2);
- Propulsion (5).

Chapter "*Securing the Air Transport*" (3).

Chapter "*Safety*" (6).

Chapter "*Air Traffic Operations*" (4).

Chapter "*Cost Efficiency*"

- Manufacturing Techniques for Engine Components (2);
- Structures and Materials (6);
- Systems and Equipment (3).

Chapter "*Pioneering the Air Transport*", after a strategy oriented paper on "A Technical Vision of Sustainable Commercial Air Transportation in 2030", 7 technological project papers are presented.

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-75

Clean Sky: Bringing Sustainable Air Transport Closer

Eric DAUTRIAT

Abstract. Funded equally by the European Commission and Europe's aeronautical industry, Clean Sky is a Joint Technology Initiative designed to speed up the technology breakthroughs needed to achieve ACARE's environmental goals. As a public-private partnership, it aims to develop, mature and validate key "clean technologies" for aviation in order to shorten the time to market for new solutions tested on Full Scale Demonstrators. With a budget estimated at €1.6 billion over 7 years, Clean Sky is expected to lead the earlier introduction of new, radically greener Air Transport products.

The following text provides a presentation of the organisation and current state of play of the initiative as well as an overview of the flagship technologies developed within the programme, each one of those leading to five observations on the promising approach of research and innovation promoted by Clean Sky.

Keywords. ACARE, aeronautics, all electric aircraft, Clean Sky, composites, full-scale demonstrators, emission reduction, Joint Technology Initiative, Joint Undertaking, flight path optimisation, FP7, innovation, laminarity, open rotor, research and technology, Technology Readiness Level

1. Introduction

"Clean Sky": the designation clearly sets the tone.

We are talking of aeronautical technologies designed to reduce the environmental footprint of future aircraft in terms of CO_2, noise, NO_X and life cycle effects.

2. The Organisation of the Clean Sky JTI

Born out of the ACARE (Advisory Council for Aeronautics Research in Europe) Strategic Research Agenda, Clean Sky is a new kind of initiative (Fig. 1).

As a "Joint Technological Initiative", it hinges on a public-private partnership associating the European Commission and just about the entire civil aircraft industry of Europe. In the course of a ten year period (2008–2017), it aims to deliver integrated demonstrators with a high TRL (Technology Readiness Level).

The total cost of the programme is 1.6 billion euros, making it one of two or three of the largest research programmes ever financed by the European Union in any field.

In addition to direct benefits to European citizens, the reduction of CO_2 emissions and noise also provides a federating objective on a technological level. Efforts will be made in the areas of aerodynamics, mass, propulsion efficiency, flight path optimisation, etc.

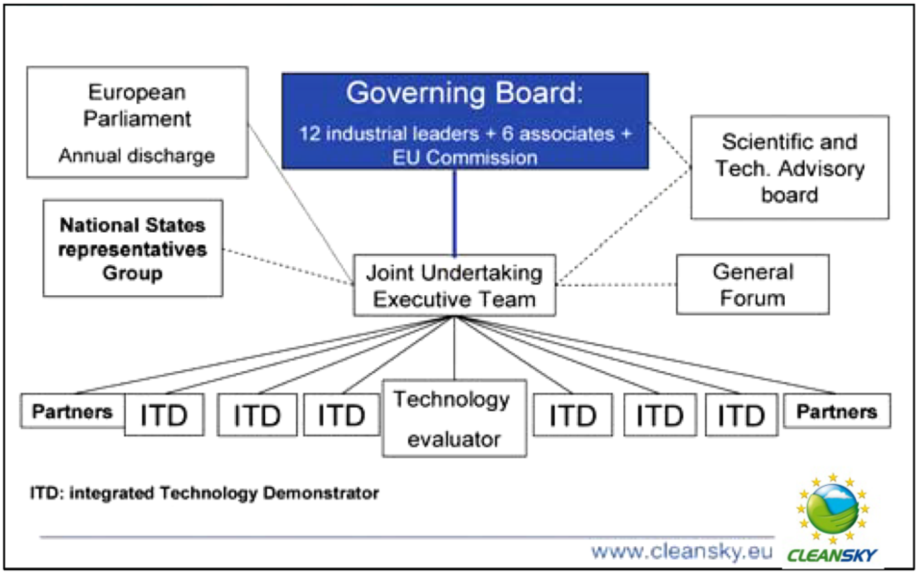


Figure 1. Organisation of the Clean Sky JTI.

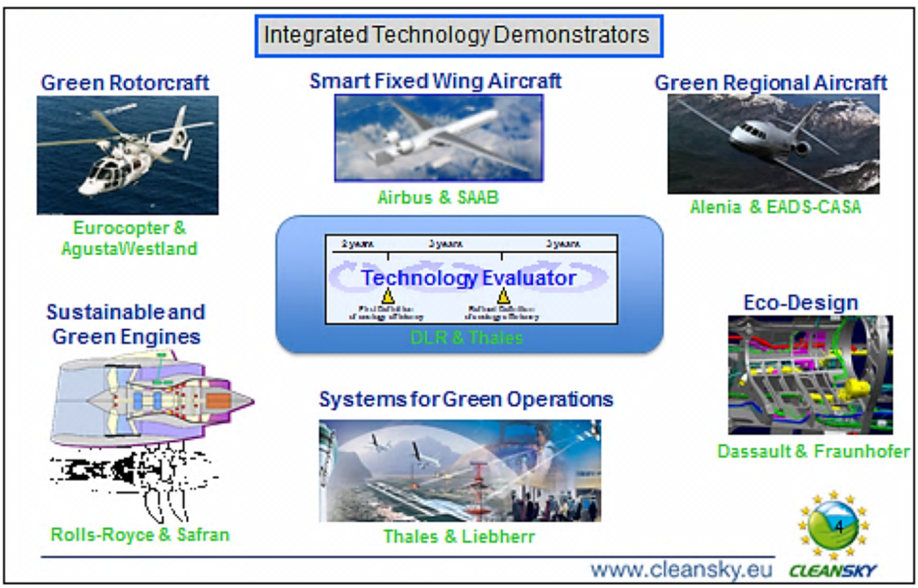


Figure 2. ITD Leaders of the Clean Sky JTI.

2.1. The ITD Leaders

The programme is organized into 6 Integrated Technology Demonstrators (ITD), technological platforms grouping together coherent research areas and the interested players (Fig. 2).

Each one is directed by a tandem of industrialists. Three of them concern aircraft directly:

- Smart Fixed-Winged Aircraft, for commercial aircraft (Airbus and Saab);
- Green Regional Aircraft (Alenia and EADS-CASA);
- Green Rotorcraft (Eurocopter and AgustaWestland);

with three further transverse topics:

- Sustainable and Green Engines (Rolls-Royce and Safran);
- Systems for Green Operations (mission and flight path management, energy management with Thales and Liebherr);
- Eco-Design (Dassault and Fraunhofer).

The whole is topped by a "Technology Evaluator", a set of models intended to identify environmental benefits on a level of an individual mission, an airport or the entire world fleet. This Evaluator is directed by Thales and the DLR – German Aerospace Center.

2.2. Associates and Partners

Around this circle of ITD leaders is a wider circle of associates: Over 70 other industrialists, research centres, SMEs (Small & Medium Enterprise) and universities, committed like the leaders for the whole duration of the programme. These include organisations as diverse as Zodiac, MTU, Onera, Ruag, the Universities of Milan and Cranfield or the Romanian INCAS.

Leaders, associates and the European Commission constitute the members of the Clean Sky Joint Undertaking, or J.U., a peculiar legal creature whose unique mission is to implement the Technological Initiative of the same name. They are represented by a governing board, which acts as both the management committee of the programme and the board of directors of the J.U.

The essence of the public-private partnership lies in the joint taking of strategic decisions. Of course, shared decision making also implies shared funding. Funds are provided half by the Commission – from the FP7 (Framework Programme for research – Euro funding and industry co-funding) budget – and half by industry. *(NB: The term "industry" is a simplification. It includes research centres and other public organisations sharing the same financing terms).*

A third circle exists, of crucial technological and political importance: The "Partners". These are selected by means of regular (more or less quarterly) calls for proposals (CfPs). They must meet precise technical specifications stemming from the requirements of the demonstrators.

In March 2011, after seven calls for proposals and the related evaluation processes which are carried out according to European Commission rules, it appears that the SMEs are representing about 40% of the winners. A total of almost 400 identified participants (including the Members) is being reached: Clean Sky is gradually involving not only the major aeronautics players, but also a significant number of newcomers.

As regards governance, the highest authority is wielded by the governing board while the management of the programme is entrusted to the Executive Director of this Joint Undertaking and his twenty-member team. The JU issues contracts to members and partners and ensures proper execution of activities; the Executive Director is directly responsible to the European Parliament.

Figure 3. Cross-sectional drawing of the Snecma Counter Rotating Open Rotor.

3. The Flagship Projects: Paving the Way

It would be tedious to cite the hundred or so key technologies and 30 demonstrator projects included in the six ITDs. A few examples will suffice in order to make some general observations.

3.1. Open Rotor

Open Rotor (Fig. 3) is the weightiest project, to the extent that Clean Sky finances two parallel projects: one by Rolls-Royce, the other by Snecma, both with geared counter-rotating pusher propulsors.

In terms of CO_2 benefit, Open Rotor is very promising with approximately 30% reduction in engine specific fuel consumption with respect to a Year 2000 reference, a little less once installed because of weight penalties for example. Problems of noise, vibration and certification have to be resolved of course, but the latest information is encouraging. One of these demonstrators will be bench tested in 2015, and subsequently flight tested on an Airbus A340-600.

This concept is in fact not entirely new, having already been tested in the United States during the 1980s' surge in fuel prices, more short-lived than today. It does though benefit from developments carried out in the past quarter of a century.

First Observation
Clean Sky aims for the medium term, the very next generation of aircraft.

3.2. Laminarity

Laminarity is another large-scale project, and a flight demonstration is also planned in 2015 on an A340, with the realisation and installation of an 8 metre-long wing element (Fig. 4).

For the moment it is a question of natural laminarity, which makes manufacturing aspects all the more essential, as well as the verification of the robustness of this laminarity along time.

Like Open Rotor, laminarity is a very promising technology that will be relevant for future aircraft generations that could enter the market around the horizon 2025.

Figure 4. BLADE – Major laminar flow demonstration.

Clean Sky provides the platform and timeframe, making the large required technological steps at the right time.

Second Observation

Clean Sky, by definition, is related to industrial strategies.

It aims to prepare, from the viewpoint of environmental technologies, future generations of planes and rotorcraft. This provides an essential guarantee – disregarding unforeseen factors which are always possible in research – that public expenditure will not be frittered away on superb but inapplicable technologies. It is also the objective of shared governance.

3.3. Flight Path Optimisation

Flight path optimisation is another effective means to reduce both CO_2 emissions and noise. In addition to the SESAR (Single European Sky ATM Research) programme, another J.U. comprising the technical side of the European Single Sky initiative, which will optimize air traffic and achieve environmental benefits by avoiding fuel waste, Clean Sky is also looking into cockpit technologies which will enable real time optimisation of an individual mission.

Third Observation

SESAR is interested in traffic, Clean Sky with the vehicle. The two programmes are partially linked and subsequently coordinated.

3.4. Composites

Research concerning composite materials (and therefore weight) is carried out within the framework of regional aircraft (Fig. 5).

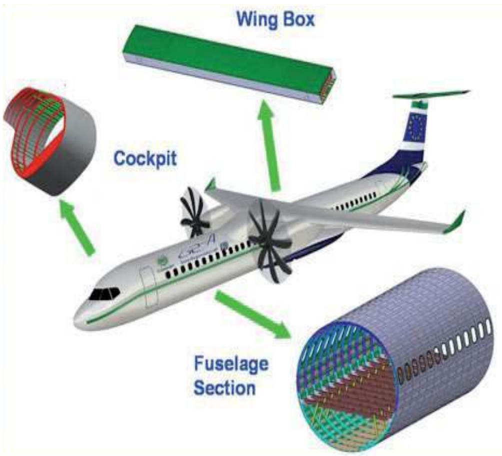


Figure 5. Next Generation Regional Aircraft with composite materials.

Some examples include carbon nanotubes in order to improve conductivity and shear strength, and multi-layer, multifunction materials.

Admittedly, Clean Sky is far from being the only party involved in research activities on composites. For large aircraft, it is carried out in other contexts.

Fourth Observation

Clean Sky is not an island; on the contrary, it has many partners, many connections with the collaborative research in FP7 or national programmes; better still, Clean Sky aims to have some leverage on the latter.

3.5. Towards All Electric Aircraft

Business aircraft, regional aircraft and helicopters coordinate part of their "all electric" activities since "all electric" or "almost all", is easier to achieve in these sectors (for reasons, in particular, of dissipated power) than for large aircraft, although the latter are not absent (Fig. 6).

Corresponding architectures will all be tested on a "Copper Bird" belonging to the "Eco-Design" ITD.

Fifth Observation

Clean Sky is a coordinated programme; with many inter actions between the different ITDs, and not a simple juxtaposition of interests.

This, together with the global nature of the technology evaluator, demands a "systems" approach which had not been a feature of European programmes until now.

4. Conclusion

Clean Sky being an aeronautical enterprise, one might say that it has now reached full cruising speed, after a delayed take-off. Initial hurdles have been overcome and the necessary budgetary flexibility and operational effectiveness achieved.

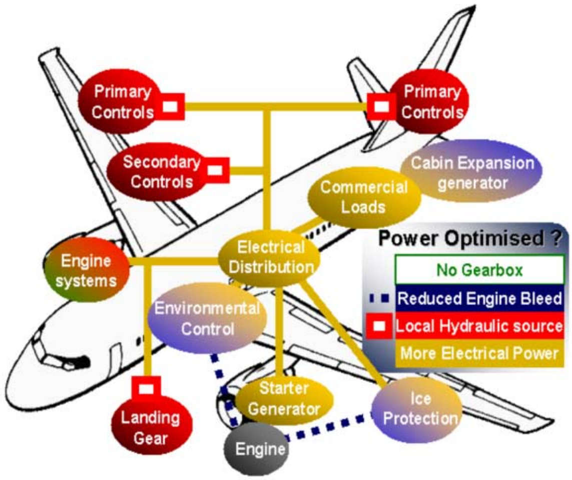


Figure 6. Potential optimised architecture.

Later, it will be up to the market to put these technologies into operation. The first intermediate achievements are emerging: Partial tests in flight, production of innovative parts, etc.

These parts of the puzzle will begin to be assembled towards 2013, when the largest demonstrators start to turn over. In the meantime, the environmental benefits are being secured.

Clean Sky has proven to be a very essential instrument in driving substantial technology advancement for the future of aeronautics.

About the author

Eric DAUTRIAT
Executive Director of the Clean Sky Joint Undertaking
Clean Sky Joint Undertaking – Av. de la Toison d'Or 56–60
4th floor - B-1060 Brussels
Tel: +32 – (0)2 221.81.52
Fax: +32-(0)2 221 81 50
eric.dautriat@cleansky.eu
http://www.cleansky.eu/

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-82

Aerodynamic Technologies for More Effective, Environmentally Friendly Air Transport System: The KATnet Strategy

Adel ABBAS, Geza SCHRAUF and Eusebio VALERO

Abstract. Most of the requirements fixed by the ACARE Vision 2020 for civil aircraft operations are conditioned by the improvement of aircraft aerodynamic performance, which necessitates using technologies able to achieve a more effective, environmentally friendly air transport system. The European coordination action so-called KATnet has identified and assessed key aerodynamic technologies that offer solutions to take up the challenges of this Vision 2020. These technologies are highlighted here below.

Keywords. Aerodynamics, swept wing, laminar flow, flow control, turbulent skin friction, drag reduction

1. Introduction

The increasing environmental awareness of European society has always been present within the aeronautical community and has had a strong influence on determining its perceptions of how future aircraft should be. In line with this, the ACARE Vision for 2020 compiled by a group of Renowned Personalities in the aeronautical field, has proposed a clear set of requirements for civil transport aircraft operation in order to reach the following specific goals:

- Five-fold reduction in accidents;
- Halving perceived aircraft noise;
- 50% cut in CO_2 emissions per passenger-km;
- 80% cut in NO_X emissions;
- Air traffic system capable of handling 16 million flights a year;
- 99 % of all flights within 15 minutes of timetable.

Most of these goals are directly related to the improvement of aircraft aerodynamic performance by employing technologies to achieve a more effective, environmentally friendly air transport system. In this context the European Coordination Action KATnet I and II (Key Aerodynamic Technologies for Aircraft Performance Improvement), financed by the European Commission was conceived. The main objective of KATnet was to support the global strategic approach of ACARE. This has been attained by the development of a common RTD strategy for identified key technology areas, and by providing a communication platform for all aircraft disciplines related directly or indirectly with aircraft performance improvement. This platform was realized by Internet, workshops and a conference on the subject. KATnet has identified and assessed key

Figure 1. Forward swept wing configuration investigated in NACRE.

aerodynamic technologies that offer the potential for the challenges of the Vision 2020 to be met and has investigated relevant implementation strategies.

These technologies can be categorised into two different groups. First, technologies aimed to reduce aircraft vortex (or induced) drag, targeting aircraft configuration. Second, technologies for viscous drag reduction (mainly skin friction) and the elimination of flow separation through the application of passive and active “flow control” technologies. These technologies are highlighted in the following sections.

2. Aircraft Configuration Technologies

Pursuing a high aspect ratio wing solution for the aircraft or adopting a wing tip device if the aircraft is span limited can reduce vortex drag at a given lift coefficient. The Aerodynamics of high aspect ratio wings for ‘Proactive Green’ wings has been extensively investigated in several projects. Further multidisciplinary work at an aircraft concept level is required and this was incorporated within the FP6 NACRE (New Aircraft Concept Research) project. Conventional wingtip devices are considered mature and Large Winglets were investigated in the FP6 AWIATOR project. Exploratory research into novel wing tip treatments was studied in the FP5 project M-DAW, resulting in a successful test in the European Transonic Wind tunnel (ETW) of the selected wingtip concept. The outcomes of these activities highlight the need for further research to address multidisciplinary, aero-elastic and structure aspects of their design.

The forward swept wing configuration (Fig. 1) offers many advantages with respect to Natural Laminar Flow (NLF) technology [4].

The lower leading edge sweep for same 50% chord line sweep yields to less cross-flow instabilities and allows a larger NLF area to be obtained (or higher cruise Mach number to be chosen). In addition, favourable stall behaviour and less wave drag are expected. The foreseen drawbacks are a larger trailing edge sweep angle which can strengthen trailing edge separation problems in the inner wing area and a tendency for static structural divergence.

3. Drag Reduction Technologies

Significant research experience in drag reduction technologies has been gained over the past years supported by a dedicated EU programme [5].

Several drag reduction concepts have been investigated with emphasis on laminar flow technologies either natural or hybrid laminar flow control. A net fuel saving of

Figure 2. ETW test carried out to calibrate transition tools (TELFONA project).

about 10% could be achieved by the laminarisation of flow over the wing, tails and nacelles.

3.1. Natural Laminar Flow (NLF)

The European research project TELFONA (Testing for Laminar Flow on New Aircraft, [7]) investigated design challenges for Natural Laminar Flow wings. The objective of the TELFONA project was to develop the tools required to design and test a Natural Laminar Flow wing, including those required for in-flight performance determination (Fig. 2).

Laminar flow airfoils have also been designed for a very light jet business aircraft in the framework of the EC-Project CESAR (Cost Effective Small Aircraft). The key factor has been determined to be the choice of the pressure distribution which has to be designed to achieve a good compromise between cross-flow and Tollmien-Schlichting instabilities.

Recently, the NLF concept has been targeted at maturing technology for nacelle applications. On a classic nacelle, the panel junctions cause laminar to turbulent transition. It has been determined that it is necessary to move these junctions (between the nose cowl lip and the external panel, the nose cowl and the fan cowl and all access panels) further downstream. Bombardier and QinetiQ have designed a laminar flow nacelle which allows a laminar flow extent of about 30% giving rise to drag reductions of 4 to 7 drag counts depending on the reference configuration.

3.2. Hybrid Laminar Flow (HLF)

Extensive research has been undertaken both at a national and European level to mature Hybrid Laminar Flow by suction. A number of successful demonstrations in wind tunnels and flight have been carried out. The technological challenges are now largely non-aerodynamic – dealing with the integration of the complex system solutions into the wing, nacelle, fin and horizontal tail primary structures.

Recently, NLF/HLFC (HLFC: Hybrid Laminar Flow Control) has been investigated for a supersonic business jet in the EC HISAC (Environmentally Friendly High Speed Aircraft) project. The main results showed that Natural Laminar Flow should be achievable on the outboard wing while suction and the use of anti-contamination devices are needed to maintain laminar flow on inboard wing (Fig. 3). A 50% chord upper surface transition location and a 30% viscous drag reduction is potentially achievable.

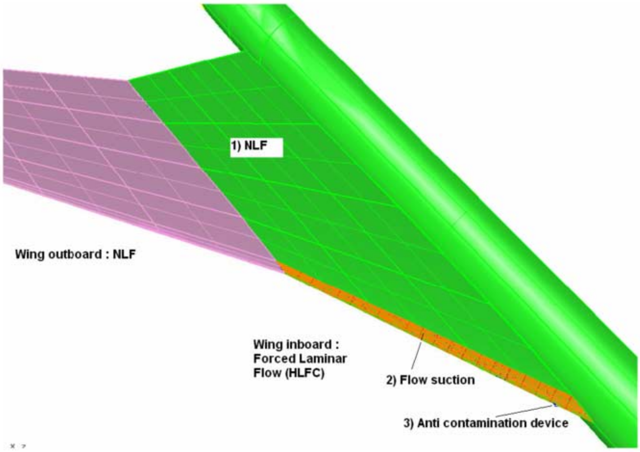


Figure 3. Applications of NLF & HLFC concept on a supersonic test (HISAC project).

In the field of supersonic aircraft, the EC SUPERTRAC project investigated the possibility of reducing skin friction drag on wings by transition control. Wind tunnel test results demonstrated a successful application of suction in supersonic flow using a sintered plate with high porosity (Reynolds number at the transition approximately 5.106). A supersonic wing designed with an optimisation process exhibits a drag reduction of 6%, compared to a fully turbulent configuration, through the use of suction and an anti-contamination device.

3.3. Alternative Laminar Flow Technology

Alternative methods for promoting laminar flow are being considered by the research community. These may become more attractive due to advances in micro and nano-machining and electro-mechanical manufacture. Technologies identified include the application of distributed roughness to delay cross-flow instabilities and the active control of Tollmien-Schlichting instabilities through the application of mass-less jets and surface actuation. Such technologies may offer lighter weight solutions than conventional hybrid laminar flow systems. More research is required to understand the viability of such approaches both in terms of the fundamental flow physics and the resultant control system requirements.

3.4. Turbulent Skin Friction Reduction

Even if the application of laminar flow technology is successful, a significant proportion of turbulent skin friction drag will still be present on the airframe, mainly on the fuselage. Riblet technology is considered an aerodynamically mature technology that could offer modest reductions (7% skin friction drag reduction) in aircraft turbulent drag. However, considerable effort must be applied to improve manufacturing technologies and material properties if these are to be successfully deployed on an aircraft without an adverse impact on maintenance.

Another example is the use of dimples technology, currently investigated by DLR. This passive treatment typically gives small levels of drag reduction and may not be attractive due to the costs associated with their implementation.

4. Separation Control Technologies

Numerous research activities on the control of flow separation are being undertaken in USA and in Europe, including many wind tunnel demonstrations [2,6]. This research allows the assessment of the effectiveness of various actuators and various concepts of actuation, as well as the optimal parameters of such devices (geometry, size, orientation, flow rate, frequency). A particular problem with this approach is that the use of small-scale wind tunnel models often necessitates the use of smaller actuators than would be needed in flight demonstrations. Moreover, for active pulsed actuators, actuation frequencies are usually an order of magnitude higher for wind tunnel demonstrations than for flight test. In the case of pneumatic actuators wind tunnel demonstrations have shown that actuator blowing jet velocities must be higher than the local external flow velocity (by a factor of about 1.5 or 2). Non-dimensional excitation frequencies of the order of 1, lead to dimensional frequencies around 1kHz for wind tunnel model demonstrations.

Typically, flow separation control technologies can be classified as: passive, active and reactive. Passive systems do not require a power input for their operation, but have in general a drag penalty during cruise operation. Vortex generators (VG) or sub-boundary layer vortex generators (SBVG) are among these. Active system requires power input for actuation. Examples of these include pulsing fluidic vortex generators, (pneumatic), and synthetic jets (electrical-mechanical electromagnetic or plasma actuators). Reactive systems, in addition to being powered require some kind of intelligence and actuate according the information supplied from a sensor system.

4.1. Passive Flow Control Devices

Passive VGs are small aspect ratio airfoils mounted normal to the lifting surfaces ahead of the flow separation point that energise the boundary layer to prevent separation. The only difference with SBVG is that the latter are submerged in the boundary layer to reduce the drag penalty.

A typical application of VG/SBVGs for buffet control was performed experimentally in the DERA 8’ high speed wind tunnel by QinetiQ. Other applications such as: improving the attachment of flows in the Pylon-wing interference or in internal flow in an S-duct engine air-intake configuration (Fig. 4) have been studied by Onera and numerically by KTH (Kungliga Tekniska Högskolan – Royal Institute of Technology, Sweden).

4.2. Active Flow Control Devices

Blowing air through slots adds energy to the boundary layer, energising the flow near the wall enabling it to overcome adverse pressure gradients. Jet entrainment has been shown to enhance the lift generated by airfoils; through exploitation of the Coanda effect. This mechanism allows a tangential surface jet sheet to remain attached even if large curvature effects are present. Both steady and unsteady (vortex generator) blow-

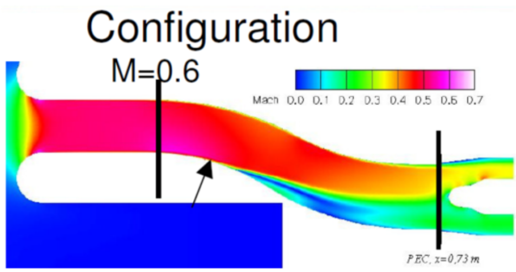


Figure 4. Flow control application to S-duct engine air-intake.

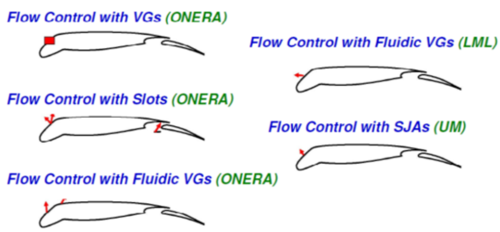


Figure 5. Different configurations to be studied in European Project AVERT.

ing technologies have been proven experimentally, with more or less success, to control boundary layer separation [1,3]. These experiments have shown that various parameters must be managed and calibrated, the most important being blowing velocity VJ and excitation frequency F in the unsteady case.

Examples of these devices have been investigated on a slat-less/flap configuration. The reduced complexity of this high-lift system allows for a weight saving estimated to be of the order of 200kg for a typical short range 150 seat aircraft. The analysis has been performed at M = 0.153 and a jet velocity of VJ = 340 m/s, where a CLmax as high as 3.5 at angles of attack of 25º has been obtained compared to an original value of 2.5.

The EC AVERT project investigated many different possibilities for the application of fluidic/synthetic jets and vortex generators for a standard high-lift configuration having a drooped nose both numerically and experimentally (Fig. 5).

5. Conclusions

This report gives an overview of key aerodynamic technologies identified by the KATNet network and shows how they are aligned with the European aerospace 2020 vision goals. It is perhaps not surprising that the biggest impact aerodynamics can potentially make is in the area of the environment – as this is directly influenced by product performance at both high and low speed.

A number of relatively low maturity technologies have been identified which could provide a further step in the direction of the 2020 vision goals and if successful could help achieve the 2020 challenges. These technologies mostly fall into the area of flow control of which 3 categories can be defined. Delay in laminar to turbulent transition – Reduction in turbulent skin friction – Flow separation control.

It is apparent that an important research plan is needed if the 2020 vision goals are to be achieved. Effort is needed not only in the area of aircraft configuration and component optimisation but also in fundamental research into the flow physics of drag generation and innovative mechanisms of flow control.

References

[1] D. Greenblatt and I.J. Wygnanski, The control of flow separation by periodic excitation, Progress in Aerospace Science, Volume 36, 2000.
[2] V. Kilbens and W. Bower, "An Overview of Active Flow Control Applications at the Boeing Company", AIAA 2004-2624.
[3] D.C. McCormick, "Boundary Layer Separation Control with Directed Synthetic Jets", AIAA 2005-519.
[4] G. Redeker and G. Wichmann, "Forward Sweep – A Favorable Concept for a Laminar Flow Wing", J. of Aircraft, Volume 28(2), 1991.
[5] J. Reneaux, Overview on drag reduction technologies for civil transport aircraft, ECCOMAS 2004.
[6] W. Sellers, G. Jones and M. Moore, "Flow Control Research at NASA Langley in Support of High Lift Augmentation", AIAA 2002-6006.
[7] T. Streit et al., The TELFONA Pathfinder Model, a Second Look, V European Conference on Computational Fluid Dynamics ECCOMAS CFD, 2010.

About the Authors

Adel Abbas is Head of Aerodynamics R&T, Flight Physics, Airbus Operations, 28906 Getafe (Madrid)
Tel.: +34 916241445
Adel.abbas@airbus.com

Geza Schrauf is Engineer, Aerodynamics R&T, Flight Physics, at Airbus Bremen
Tel.: +49 4215383232
Geza.schrauf@airbus.com

Eusebio Valero is Professor of Applied Mathematics Department, Universidad Politécnica of Madrid
Tel.: +34 913366326
Eusebio.valero@upm.es

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-89

NODESIM–CFD: Non-Deterministic Simulation for CFD Based Design Methodologies

Charles HIRSCH

Abstract. As of today, analysis and design methods in aeronautical industry are based on simulations with a unique set of input data and model variables. But real operating conditions are a superposition of numerous uncertainties under which the industrial products operate, the presence of which is a major source of risk in the design decision process. The European project "NODESIM-CFD" (Non Deterministic Simulation for CFD Based Design Methodologies) – www.nodesim.eu – aims at providing tools able to evaluate and quantify uncertainties in aerodynamic and thermal performance predictions, thus contributing to support the goals of enhanced design confidence, risk reduction and improved safety.

Keywords. Non-deterministic simulation, CFD, Monte-Carlo method, Polynomial Chaos method

1. Introduction

Presently, the analysis and design methods employed by the aeronautical industry, particularly CFD simulation tools and their multidisciplinary extensions for fluid-structure, fluid-thermal or aero-acoustics applications, rely heavily on the concept of deterministic simulation, which for a unique set of input data and model variables predicts single valued output quantities. Nevertheless, the reality shows that the operating conditions are a superposition of numerous uncertainties under which the industrial products are functioning, their presence being a major source of risk in the design decision processes. Therefore, a new paradigm for CFD based virtual prototyping emerged, aiming to incorporate these uncertainties in the simulation process. This is the non-deterministic simulation, which predicts for an output quantity an entire domain of variation. In what follows, the outcomes of the efforts of the NODESIM-CFD consortium related to the development of non-deterministic methodologies that have been incorporated in software tools for the identification and quantification of uncertainties in industrial oriented applications are summarized. In addition the "lessons" learned and directions to be pursued in order to achieve industrial readiness of the developed methodologies are sketched.

2. NODESIM-CFD's Objectives and Achievements

17 teams from the aeronautical and power generation fields, research establishments and universities joined their efforts and resources in the European project NODESIM-

CFD in order to address the following topic: accounting for operational and geometrical uncertainties in the CFD simulation tools. Consequently, their efforts have been focused on the following measurable scientific and technological objectives: identification and quantification of the uncertainty parameters; development of several non-deterministic methodologies; application of these methodologies to subsystems and systems; introduction of the non-deterministic simulations into the design and decision process; stimulate the scientific co-operation and transfer of knowledge within the consortium.

Uncertainties associated to a wide variety of aeronautical applications covering domains of application as engine aerodynamics, wing aerodynamics, conjugate heat transfer and fluid-structure interactions have been identified and sorted in three classes: operational, geometrical and "numerical" uncertainties. Among the operational ones we are mentioning the Mach number, angle of incidence, Reynolds number while for the geometrical ones the expert opinion pointed to the manufacturing issues, dynamic distortion or degrading factors [3]. "Numerical" uncertainties refer, in a generic way, to the physical modeling uncertainties and the numerical sensitivities related to the imposition of boundary conditions and selection of various numerical parameters governing the computation [2,3]. We underline that in NODESIM-CFD project a clear distinction between the concepts of uncertainty and error has been accepted in the spirit of [7]. Also, the problem of assigning a probabilistic description to the random variables associated with each identified uncertainties has been addressed. In this respect, two software tools have been available in consortium: the first one being able to define a beta probability density function (PDF) starting from an expert opinion expressed as the maximum, minimum and the most likely value of the uncertain parameter and the second one being able to fit a textbook-PDF over an experimental histogram of the uncertainty.

Regarding the development of non-deterministic methodologies consortium focused on the most promising ones such as perturbation techniques and adjoint based methods, efficient Monte Carlo methods and Polynomial Chaos methods (PCMs). The developed methods have been able to predict ranges of variation, marked by computed "error" bars, for the output quantities of interest. One of the most important findings, with consequences for the validation process, has been that there are differences between the deterministic predictions obtained for the imposed mean values of the considered uncertainty and the mean values of the non-deterministic simulations (Fig. 1).

The next objective consisted of validating the developed non-deterministic methodologies by applying them in test cases, ranging as level of complexity, from academic to industrial ones. Several teams incorporated few of these methodologies in their optimization environments in order to test their potential in achieving robust designs for airfoils and blades. The line of actions of the validation process intersected with that associated to the last objective dedicated to the transfer of knowledge, which looked for offering the developers' support to the industrial "end-user" partners. With respect to the external dissemination, the most important action was the organization of the "NODESIM-CFD Workshop on Quantification of CFD uncertainties" (http://www.nodesim.eu/workshop.html). To our knowledge this was the first "non-deterministic" workshop having as one of the objectives the assessment of non-deterministic methodologies on test cases with imposed uncertainties.

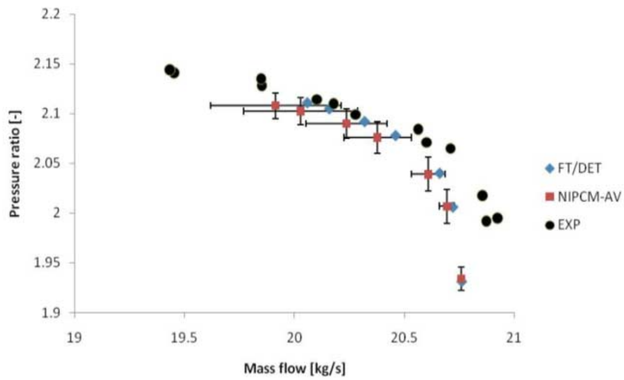


Figure 1. Pressure ratio vs. mass flow performance map for the NASA Rotor 37; operational uncertainty imposed on the outlet static pressure; square marker – 2nd order solution obtained with a Non-Intrusive Probabilistic Collocation method; diamond marker – deterministic solution; (the "error" bars represent variations in [–σ/2,+σ/2]; σ = standard deviation).

3. Lessons Learned and Findings

Some of the major findings of the NODESIM-CFD project are summarized hereafter:

- Considering the uncertainties in the simulation process asks, in our opinion, grounding the validation process on non-deterministic results, while the experimentalists should be asked providing measured data of the intrinsic uncertainties of their equipment;
- The precise form of the PDF of the input uncertainties has a strong effect on the predictions of the standard deviation and mean values for the PDF of the output variables;
- Promising non-deterministic methodologies have been demonstrated;
- The effects of numerical 'noise' of the CFD codes and their convergence behaviour on the output uncertainty predictions have been identified, but further efforts are needed for understanding and controlling these effects;
- The presence of a discontinuity in the response of the investigated system poses difficulties in computing accurately a non-deterministic solution;
- The general treatment of geometrical uncertainties has not been addressed to a sufficient level;
- Devising robust formulation of the objective/constraint functions for the robust design is still largely an open question, as it can affect significantly the design outcome;
- All the evidence gained relies on test problems with very few uncertainties.

4. Towards Industrial Readiness

In order to use the current uncertainty quantification (UQ) methods in real life applications, technology readiness levels (TRL) of 5–6 should be reached. In addition to the

known challenges in UQ community, as the curse of dimensionality (i.e., handling large number of uncertainties), the treatment of geometrical uncertainties and the quantification of the input uncertainties from scarce experimental data, the following particular ones in the realm of CFD have been pinned down in a recent literature survey performed by us: the discontinuous stochastic responses due to the presence of shock waves; the influence of the convergence level of the flow solver and various numerical sensitivities on the non-deterministic predictions and the robust formulation of the objectives and constraints in the robust design and optimisation.

The efficient management of the curse of dimensionality seems to indicate as the most promising methods those based on sensitivity analysis with adjoined formulation and automatic differentiation, while for the Monte-Carlo methods improvements of the sampling techniques are expected [8]. Regarding the non-intrusive PCMs the usage of the adaptive sparse grids in the probabilistic space appears as an interesting solution [4]. The treatment of the geometrical uncertainties is extremely challenging for intrusive PCMs where these are modeled as random fields and must be decomposed in a collection of random variables. One option is to use the Principal Component Analysis [5]. For the quantification of input uncertainties from scarce experimental data, techniques developed in the realm of computational mechanics intend solving inverse problems employing Polynomial Chaos expansions [1] or Bayesian inference approach [6] deserve special attention. The investigations on the influence of the convergence level and numerical sensitivities are to be driven by the research on the adaptive sampling techniques in the stochastic space and CFD-mesh adaptation. Adding adaptive features to Monte-Carlo methods and PCMs is suggested as being the path to be followed in handling the effects of the discontinuities in system’s response caused by the shock waves.

Finally, validation has to be accompanied by an effort directed to the building of UQ-databases containing dedicated industrial computational challenges with clear target performances which must be tackled by the current available non-deterministic methodologies.

References

[1] M. Arnst, R. Ghanem, and C. Soize, Identification of Bayesian posteriors for coefficients of chaos expansions, Journal of Computational Physics, 229 (9), 3134–3154.

[2] V. Couaillier and M. Delbos, Accurate Boundary Conditions with classical and higher order CFD methods, NATO RTO-AVT-147 Symposium on “Computational Uncertainty in Military Vehicle Design”, 3–6th December 2007, Athens, Greece, Paper 29.

[3] T.P. Evans, P. Tattersall, and J.J. Doherty, Identification and quantification of uncertainty sources in aircraft related CFD computations – An industrial perspective, NATO RTO-AVT-147 Symposium on “Computational Uncertainty in Military Vehicle Design”, 3–6th December 2007, Athens, Greece, Paper 6.

[4] B. Ganapathysubramanian and N. Zabaras, Sparse grid collocation schemes for stochastic natural convection problems, Journal of Computational Physics, 225, 652–685.

[5] V. Garzon, Probabilistic Aerothermal Design of Compressor Airfoils, PhD Thesis, Massachusetts Institute of Technology, 2003.

[6] Y.M. Marzouk and H.N. Najm, Dimensionality reduction and polynomial chaos acceleration of Bayesian inference in inverse problems, Journal of Computational Physics, 228, 1862–1902.

[7] W.L. Oberkampf, T.G. Truncano, and C. Hirsch, Verification, validation, and predictive capability in computational science and physics, Applied Mechanics Review, 57 (5), 345–384.
[8] J. Peter, M. Marcelet, S. Burguburu, and V. Pediroda, Comparison of surrogate models for the actual optimization of a 2D turbomachinery flow, In Proc. of the 7th WSEAS International Conference on Simulation, Modelling and Optimization (SMO'07), ISSN: 1790-5117, ISBN: 978-960-6766-05-3, 2007, 46–51.

About the Author

Charles Hirsch is Prof. Emerite at Vrije Universteit of Brussels (Belgium)
President of Numeca International S.A.
Chaussée de la Hulpe, 189. B-1170 Brussels
charles.hirsch@numeca.be
www.numeca.be

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-94

Morphing High Lift Structures: Smart Leading Edge Device and Smart Single Slotted Flap

Hans Peter MONNER and Johannes RIEMENSCHNEIDER

Abstract. With 13 partners from 8 countries the EU project SADE (Smart High Lift Devices for Next Generation Wings) aims at making a major step forward in the development and evaluation of the potential of morphing airframe technologies. The project contributes to the research work called for to achieve the reduction of carbon dioxide and nitrogen oxide emissions through new, intelligent, low-weight structures. Research into 'smart' structures and morphing airframes will open up new horizons in lightweight aircraft design.

Keywords. Morphing, smart high lift configuration, leading edge skin, closure flap ribs, slotted flap

1. Introduction – The "SADE" Project

All aerodynamic concepts for the significant reduction of drag such as laminarisation require thin, high-aspect-ratio wings. However, state-of-the-art high-lift systems will suffer from the reduced construction space and do not cope with the requirement for surface quality and accuracy. Thus, the SADE project is looking to develop suitable 'morphing' high lift devices: The seamless 'smart leading edge device' is an indispensable enabler for laminar wings and offers a great benefit for the reduction of acoustic emissions. The 'smart single slotted flap' with active camber capability permits a further increase in lift (Fig. 1). Thanks to their ability to adapt the wing's shape, both devices also offer aerodynamic benefits for cruise flight.

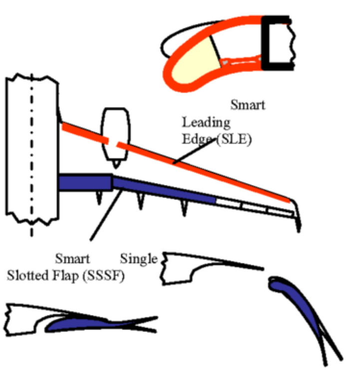


Figure 1. SADE smart high lift configurations (Source: DLR).

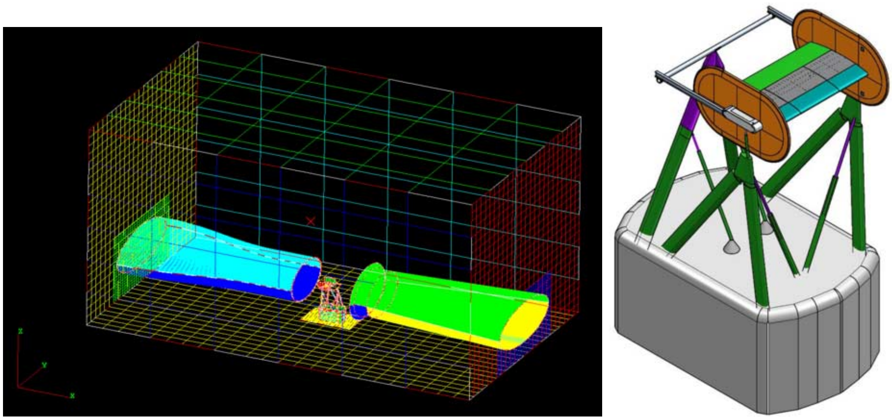


Figure 2. Aeroelastic model of wind tunnel experiment with open section (Source left: FOI) and CAD model of WT mount (Source right: TsAGI).

SADE builds on available promising concepts for smart structures. The technological realisation and optimisation of these concepts towards the special requirements of full-scale systems is the most essential challenge for morphing today. Another challenge results from the aeroelastic condition that the structural system is optimised for. Hence, a realistic full-scale section of a morphing wing will be manufactured and tested in the TsAGI T101 wind tunnel for an investigation of these effects. Some selected results of SADE will be described subsequently.

Besides the actual research work, it is an important goal of the project to share the research results with the research community in Europe. That is why the consortia organised a dedicated SADE session at the first EASN (European Aeronautics Science Network) Workshop on Aero-structures in October 2010 in Paris, presenting a wide spectrum of project results including:

- Design strategies for high lift devices;
- The design of variable stiffness skins and selectively deformable structures;
- The aeroelastic and aerodynamic analysis of novel high lift devices.

2. Work Related to the Wind Tunnel

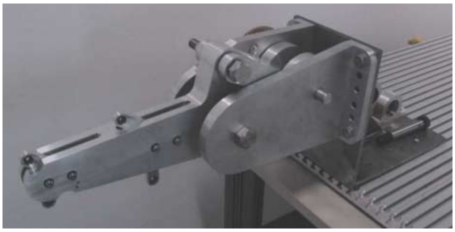
2.1. Preparation

According to the results of the aerodynamic investigations for loads and shapes the structural design for the wind tunnel model has been carried out. This involved the structural design of the wing section comprising a smart leading edge, wing box and trailing edge flap as well as the end plates and wind tunnel mounting. Additionally, to ensure safe operation, a complete aeroelastic and aerodynamic design (Fig. 2) of the wind tunnel test section was required. Flutter stability and the influence of the tunnel and the aspect ratio of the model with its end plates have also been investigated.

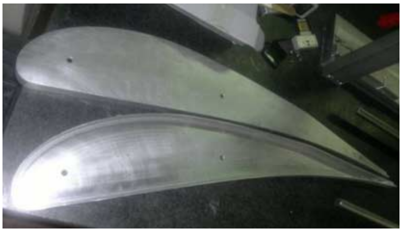
The wind tunnel model itself will be a five meter section of a FNG (Flügel Neuer Generation) wing with a chord of 3 meters and a rectangular plan form. It will be

a) Leading edge skin (DLR).

c) Wing box (TsAGI).



b) Kinematics (EADS).



d) Closure flap ribs (PAI).

Figure 3.

equipped with a flexible nose and a conventional flap, which can be placed into cruise, take off and landing positions. The wing box and the flap are conventionally manufactured of metal, the skin of the nose is made of Glass Fibre Reinforced Plastic (GFRP) as the flexibility and strength of this skin is crucial for the success of such a gapless droop nose. The model will be instrumented with three chord-wise sections of pressure tubes and strain gauges within the morphing part of the model and the kinematic linkages. It is planned to use optical measurements to evaluate the displacement of the leading edge under loading conditions.

2.2. Hardware

Currently the hardware is being manufactured (Figs 3a, b, c, d) by different partners: DLR provides the leading edge skin, EADS IW supplies the kinematics, the trailing edge with the flaps and the mounting plates are manufactured by Piaggio and the wing box and side plates as well as the connections to the mount of the wind tunnel are manufactured by TsAGI. Assembly of the different parts is an ongoing task presently being undertaken at EADS and later at TsAGI.

2.3. Droop Nose Design for Wind Tunnel

As the flaps and wing box are rather conventional in their design, the seamless smart leading edge is designed to be flexible enough to be morphed into the take off and

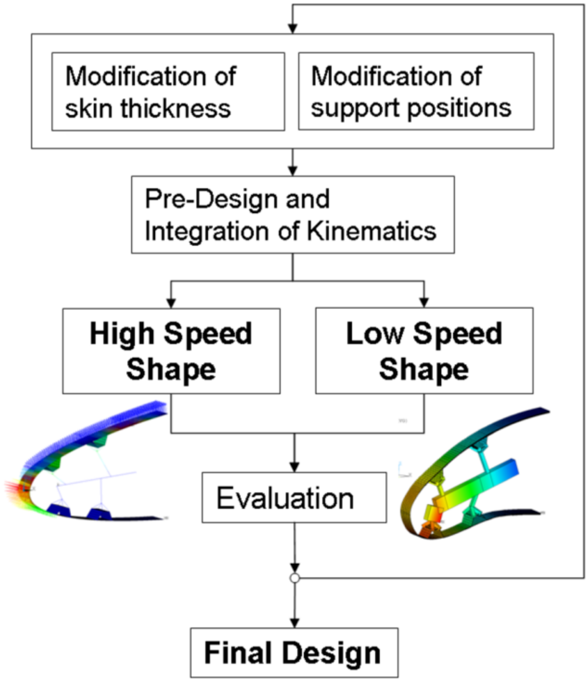


Figure 4. Smart Leading Edge design cycle (Source: DLR).

landing shape, but strong enough to carry the aerodynamic loads into the substructure and to bear the strains of morphing. In order to do so, a skin design process has been established, which allows the tailoring of the skin thickness in a way that the displacements introduced by the kinematics will morph the skin into the desired shape. Also the load introduction into the skin is of interest. Omega stringers were designed to distribute the load of morphing deflections into the skin, taking into account the stability and strength of the stringers. The difference between the aerodynamic target shape and the achieved shape is within tolerable limits. Besides the skin it is an important task to design the kinematics to deploy the droop nose to a position of approx. 18 degrees. The kinematics has to achieve the trajectories derived from structural investigations of the skin with minimum deviations, allow continuous movement (no raster) and it has to keep driving moments low for the fully retracted and fully deflected positions. Another requirement is to ensure that only one actuator is required per span wise station. The results of the skin and kinematic design were combined and a final strength calculation was carried out.

3. Materials and Structures

A crucial part of all morphing structures are the materials and structures that allow the morphing on one hand but at the same time carrying of the applied loads. Several activities within SADE deal with such materials and structures. Selected results are presented in this section.

Figure 5. FMC-UD-pre-preg (Source: EADS).

3.1. Flexible Matrix Composites

To reduce system-complexity of a droop nose with a compliant mechanism one solution is to continuously support the skin through a system of inflatable actuation-tubes. This actuation concept will work pneumatically and make use of flexible matrix composites (FMC).

These FMCs are a combination of highly flexible materials such as rubber and very stiff continuous fibres (carbon or glass fibres). These materials enable high flexibility in one direction while being very stiff in the other. Combining a tube-like geometry and a variable fibre-angle lay-up enables a wide range of deformation possibilities. A study of the possible material combinations for the manufacturing of FMCs and the production methods thereof were carried out by EADS, testing rubber, silicone and thermoplastic elastomer matrices with carbon fibres using different production methods. One focus was the creation of a production capability for large quantities of easy-to-use off-the-shelf material, similar to pre-preg material for "classical" composite materials. Test specimens based on the gained knowledge were manufactured and characterised for their mechanical properties.

The results are twofold, on the one hand a technology has been identified with which FMC can be reliably produced and on the other hand a suitable material-combination has been found. The experiments with the various production processes and materials proved pultrusion and pressure moulding as the leading technologies to create flexible matrix composites. In particular, pultrusion enables the production of a constant quality of pre-preg FMCs (Fig. 5).

For pressure moulding to become a viable production technique a way has to be found to properly restrain the fibres to avoid undulations. If the fibre-placement could be ensured pressure moulding could still not be used to create the finished product. It is still necessary to first create a wrought material from which the final layup can be realised.

3.2. Variable Stiffness Skin

Another activity within the project is dealing with tailored variable stiffness skins and actuation topologies as a solution to the dilemma of having a high stiffness to withstand aerodynamic loading, and low stiffness to enable morphing. Such a variable stiffness skin is achieved by a spatial fibre angle and skin thickness variation. The tailored stiffness distribution beneficially influences the structural deformation. A realistic skin

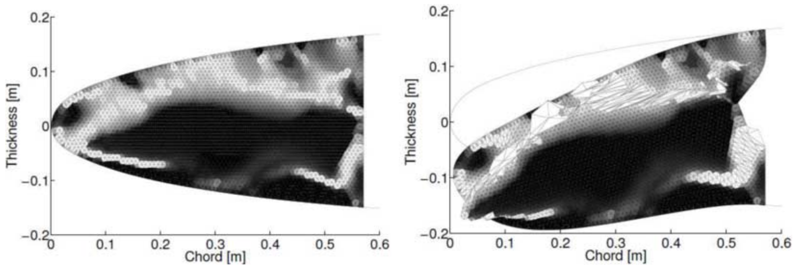


Figure 6. Deformed and un-deformed actuation topology (Source: TUD).

stiffness has been designed by TUD while taking the actuation and varying aerodynamic loads into account. In addition to this skin optimisation a combined skin/actuation topology optimisation was carried out for the leading edge of the FNG wing – for now neglecting aerodynamic loads. For the topology optimisation a fixed region (connection to the spar) and the position of the actuation load are given. The actuation element density is optimised considering skin strain constraints. The results are 2D stiffness distributions over the leading edge, which indicate regions for hinges and levers (Fig. 6).

Hinge locations are predicted by the optimiser as areas with a reduced stiffness. Such an optimisation result can be seen in the following figures. Such optimisations are very useful to simulate and to design next generation leading edge topology.

4. Virtual Aircraft

Besides the analysis of individual concepts there is an activity within SADE to establish a tool chain for coupled fluid-structure analysis in the range of medium to high fidelity. These analyses include the execution of non-linear aero-structural analysis loops and calculation of the deformed shapes and stresses under structural load and flow parameter variations. In addition, the tool extracts aerodynamic performance data, such as cp, for the selected flow parameter variations.

Starting from the structural Finite Element (FE) model, wing profile data and aerodynamic parameters, the tool attempts to automate the analysis process (Fig. 7). In the current version the 2Dimensional fluid mesh and the FE model for mesh deformation are generated automatically (Fig. 8). The mesh deformation model is the same as the aerodynamic mesh but the elements are specifically devised 'mesh deformation elements'.

Fluid-structure coupling is based on a promising novel approach, the 'common mesh refinement' method, which allows for smooth field transfer, preserving forces and moments. The field transfer process is integrated in the structural code in the form of special field transfer surface elements, which are solved together with the structural elements. The tool chain is now capable of carrying out droop nose deformation analysis with aerodynamic loads applied. This is illustrated with an analysis of one of the wing profiles studied within SADE (DLR F15 profile with flaps deployed) and a deformable leading edge (Cranfield structural model) in Fig. 9.

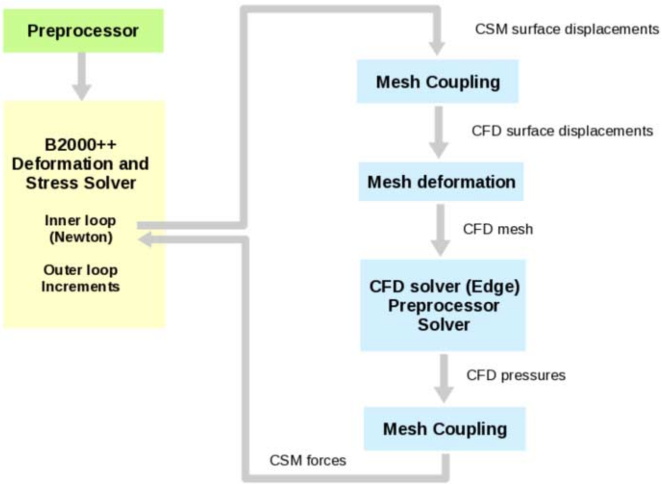


Figure 7. Schematic view of virtual aircraft tool chain (Source: SMR – Swiss engineering and development company).

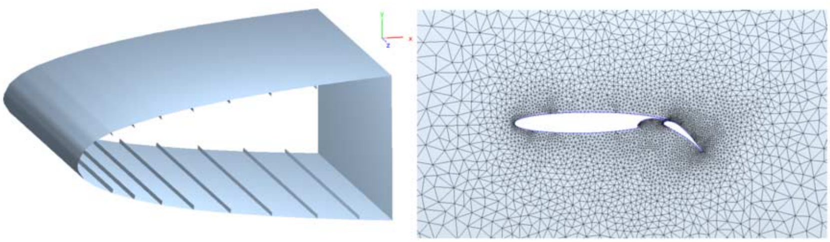


Figure 8. FE model (left) and CFD model (right) (source: SMR).

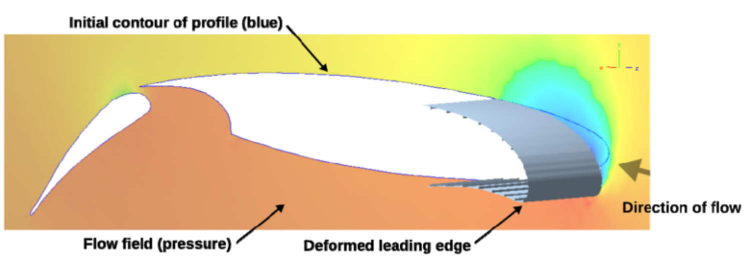


Figure 9. Coupled deformation analysis of droop nose (source: SMR).

The goal of the analysis is to calculate deformation and stresses of the structure under aerodynamic and structural loads, the actuation loads being defined by boundary conditions causing large deformations of the leading edge and by the aerodynamic loads of the deformed wing profile. The tool loops automatically over discrete values of the angle of attack analysis parameter, producing synthesis plots such as lift coefficient against angle of attack plot.

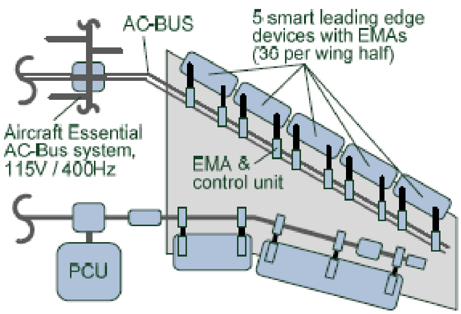


Figure 10. System Topology for the Kinematic Chain Concept (source: RWTH – Rheinisch Westfälische Technische Hochschule Aachen).

5. Concept Evaluation

To round up the project an evaluation of these concepts on an aircraft level has been developed. The ILR Preliminary Aircraft Design Suite was enhanced so that it can estimate such influences. To do that a high-lift model, based on the major system components for the conventional reference system containing slats and single-slotted Fowler flaps with standard hydraulic actuation has been established (Fig. 10).

This model has then implemented into the model for the entire conventional systems architecture of a transport aircraft. The modular implementation allows for an easy integration of innovative systems into the overall systems architecture. The model allows estimates on mass and energy consumption of the different aircraft systems, whereas the different energy systems (hydraulics, electrics and pneumatics) are sized by their consumers. The assessment on an aircraft-level becomes possible, since all repercussions of system integration are accounted for by the model.

The System topology for the kinematic chain concept is shown in Fig. 10.

Selected Publications

At the 1st EASN Association Workshop on Aero-structures in Paris the SADE consortium contributed an entire session with eight presentations. The following publications are just a small selection of the full list of publications, which can be found on the SADE web site.

– H.P. Monner and J. Riemenschneider, "Morphing high lift structures: Smart leading edge device and smart single slotted flap", Aerodays 2011, 30 March – 1st April 2011, Madrid, Spain.
– M. Kintscher, "Experimental Testing of a Smart Leading Edge High Lift Device for Commercial Transportation Aircrafts", 27th Congress of the International Council of the Aeronautical Sciences (ICAS), 19 – 24 September 2010, Nice, France.
– N. Di Matteo, S. Guo and R. Morishima, "Aeroelastic Modelling and Analysis of a Wing with Morphing High Lift Devices", International Forum on Aeroelasticity and Structural Dynamics (IFASD), Paris, June 2011-06-09.
– E. Anton Lammering and R. Henke, "Technology Assessment on Aircraft-Level: Modelling of Innovative Aircraft Systems in Conceptual Aircraft Design", 10th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference, Fort Worth, Texas, Sep. 13–15, 2010.

About the Authors

Dr-Ing. Hans Peter Monner, Head of the Adaptronics Department at DLR-Braunschweig, is project Coordinator of the European SADE Project
Hans.Monner@dlr.de
+49 531 295 23 14

Dr-Ing. Johannes Riemennschneider is Deputy Head of the Adaptronics Department
Johannes.Riemenschneider@dlr.de
DLR – German Aerospace Center
Institute of Composite Structures and Adaptive Systems
Lilienthalplatz 7
38108 Braunschweig (Germany)

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-103

Flow Control by Plasmas in the PLASMAERO Project

Daniel CARUANA

Abstract. With the continued objective of increasing aircraft performances whilst reducing the environmental impact, research is being carried out to find innovative solutions to influence air flow using simple actuators. If the aerodynamic configuration of future aircraft could be modified in real time in flight, then the aircraft's performance could be continually adapted to provide optimum aerodynamic characteristics. Among the innovative solutions, the use of plasma technologies has shown itself to be very promising from both a performance point of view and in terms of the diversity in potential applications from external and internal flow control, combustion, enhancement and noise attenuation. The main advantages of plasmas devices are their manufacturing and integration simplicity, low power consumption, ability for real time control at high frequency and their robustness.

Keywords. Plasma, PLASMAERO, plasma synthetic jet, dielectric barrier discharge

1. Introduction: PLASMAERO Project Identity Card, Consortium and Objectives

PLASMAERO is a European project of the Seventh Framework Programme, partly funded by the European Commission and coordinated by ONERA. The PLASMAERO consortium is composed of 11 organisations from seven different countries (Arttic, CIRA, CNRS, Darmstadt University, EPFL, Imp, NLR, Nottingham University, Onera, Snecma, Southampton University). The project began on the 1st October 2009 and will have a three-year duration.

PLASMAERO seeks to demonstrate how surface & spark discharge plasma actuators could be used to control aircraft aerodynamic flows. This will be achieved through an enhanced understanding of their physical characteristics and an in-depth study of how they may be optimised to influence the air flow properties. The project objectives are to:

- Understand, model and classify, through experimental and numerical studies, the most relevant physical characteristics of surface and jet plasma actuators capable of influencing airflow;
- Perform comparative experimental tests and numerical studies of different actuator configurations to select the most promising for further development;
- Demonstrate through wind tunnel experimentations the ability of plasma devices to significantly better improve the aerodynamics in representative aeronautical airflow conditions;

- Demonstrate the ease of use and installation of these actuators in a reduced size flight platform;
- Provide exhaustive recommendations on future work to be performed to achieve the implementation of this technology base on next generation aircraft programmes.

PLASMAERO is broken down into 4 main technical subjects each of which possesses specific technical objectives.

2. Plasmas Devices for Aerodynamics Developed in PLASMAERO

The possible use of plasmas to manipulate airflow was identified in the mid 1990s, but studies on flow control using plasma actuators was only started in 2000 [1]. Plasmas actuators are considered as active devices because they add energy to the flow. Three types of plasma actuators are being developed in the PLASMAERO project.

2.1. Dielectric Barrier Discharge (DBD)

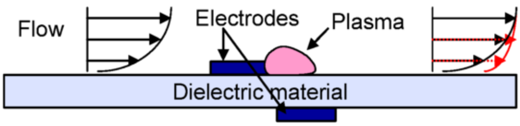
The Dielectric Barrier Discharge (DBD) device where a non-thermal plasma is generated by the application of a high-voltage discharge between two electrodes (5 to 50 kV). It creates an ionisation field and generates regions where the density of one species, positive or negative ions is dominant. Amongst the outcomes is a corresponding ion wind due to the movement of ions at the surface of the airfoil very close to the wall. DBDs are known to produce Ionic Wind (I.W.) velocities up to 6 m/s but on a surface area and very close to the wall. New devices being developed in PLASMAERO, called “saw-like” and “floating DBD”, have demonstrated ionic wind velocities up to 10 m/s (Fig. 1) [2,3].

2.2. Nanosecond Pulsed Dielectric Barrier Discharge (ns-DBD)

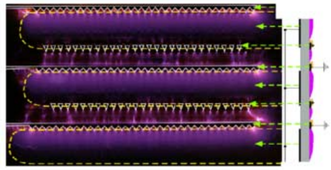
The Nanosecond Pulsed Dielectric Barrier Discharge (ns-DBD) where the voltage between electrodes increases in a few nanoseconds. The discharge regime is quite different than for DBD devices. The “nanosecond regime” is characterized by the development of synchronized, high current streamers at each rise or decay of the voltage, without any corona phase. Recent work [4,5] shows that during nanosecond discharges, a large amount of energy is deposited by the discharge at the tip of the top electrode. A large part of this energy is quickly converted into gas heating in this small region which is responsible for the generation of micro-shock waves (Fig. 2).

2.3. Plasma Synthetic Jet (PSG)

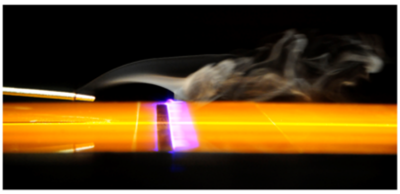
The Plasma Synthetic jet where a spark-plasma positioned inside a micro-cavity containing a small orifice adjacent to the surface, causes an electro-thermally heating of the gas inside it which leads to a rapid increase in internal pressure. This high-pressure gas issues through the orifice and forms a high velocity, hot pulsed plasma micro-jet. Once the jet issues from the cavity, it creates a partial vacuum inside the cavity. Ambient gas is then drawn into the cavity which recharges it for the next pulse. The characteristics of this device depend on the cavity geometry, the energy deposition and on the electri-



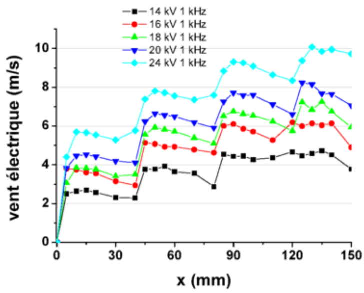
a) Principle of DBD actuator.



b) Floating-DBD.



c) Ion wind smoke visualization.



d) I.W. measurements.

Figure 1. Ionic wind by DBD.

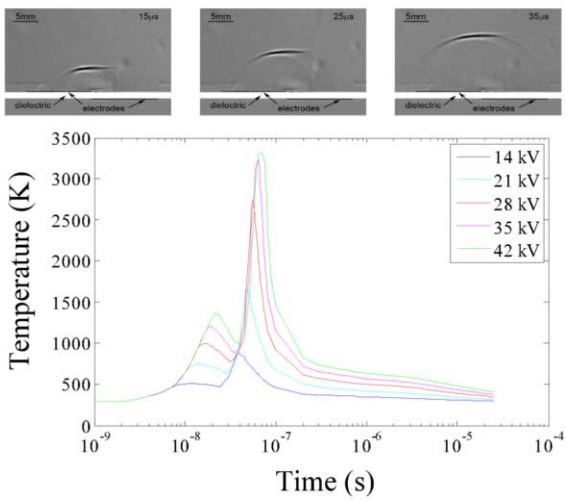


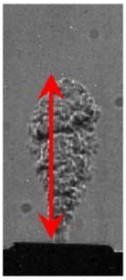
Figure 2. ns-DBD – Schlieren visualisation and computational temperature parametric study.

cal parameters. The PSJ can produce a jet velocity up to 300 m/s and pulsation frequencies up to 2500 Hz (Fig. 3) [6,7].

3. PLASMAERO Aerodynamic Applications – Mid-Term Project

The mass flow produced by the chosen plasma devices will be used in different ways to improve aerodynamics (separations, tip vortex, boundary layer transition, flap noise and shock/boundary layer interaction application).

a) PSJ device – ϕ 8 mm



b) 2 cm

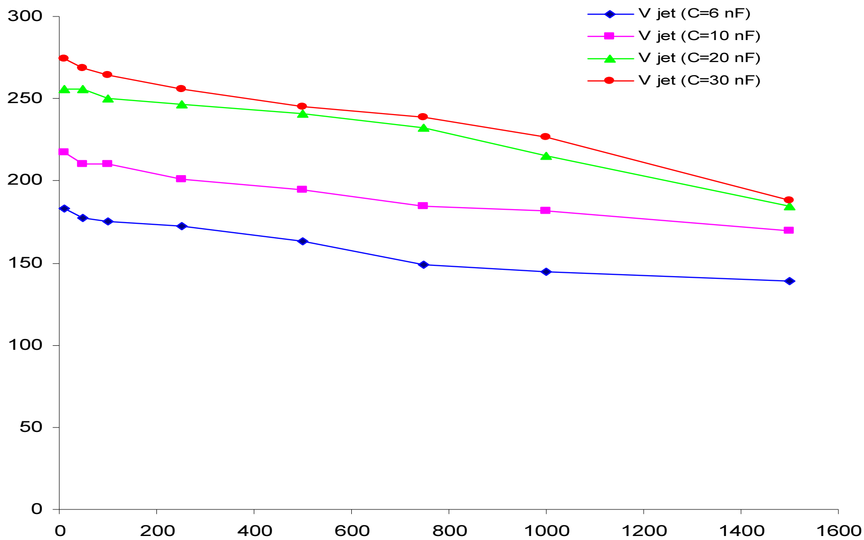


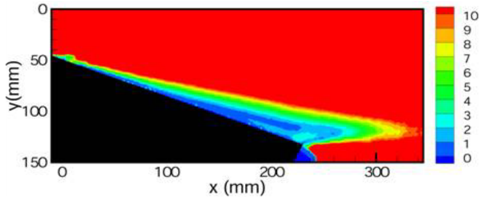
Figure 3. PSJ device (ϕ 8 mm) & generated micro-jet – ϕ orifice = 1mm – V = 300 m/s.

3.1. Separation Delay

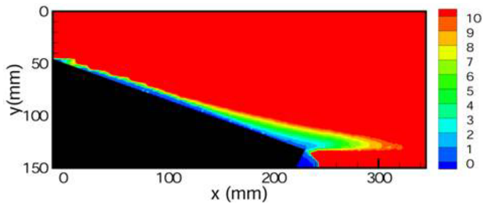
For separation delay, the control strategy is to add energy to the boundary layer directly by generation of ionic winds close to the wall (DBD) or by the generation of vortices (wall jet DBD or PSJ) to reattach the separated flow (Fig. 4). The first tests results have shown an important reduction of the separation area, particularly for the 35m/s mean flow velocity (highest tested), which could increase lift and delay the stall angle of the aerofoil by several degrees of incidence.

3.2. Boundary Layer Transition Delay

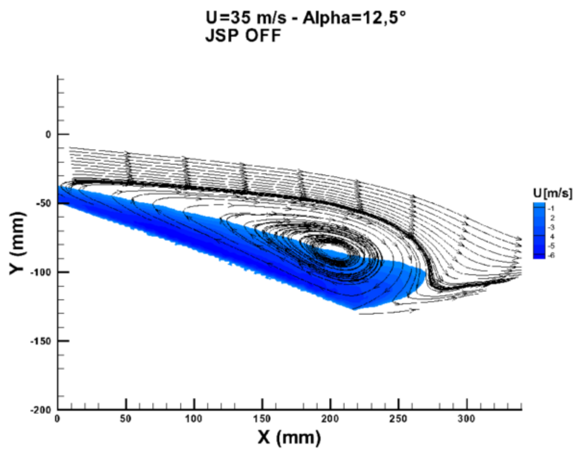
For boundary layer transition delay, DBD plasma actuators have been used in order to modify the transition location by the generation of an ionic wind parallel to the wall of the model which is able to change the boundary layer characteristics and hence to exert an effect on the skin friction and delay transition from laminar to turbulent flow (Fig. 5) [8].



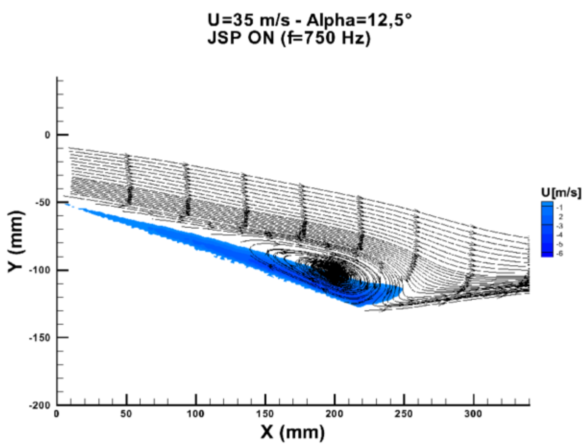
a) Separated (DBD off)



b) Re-attached (DBD on)

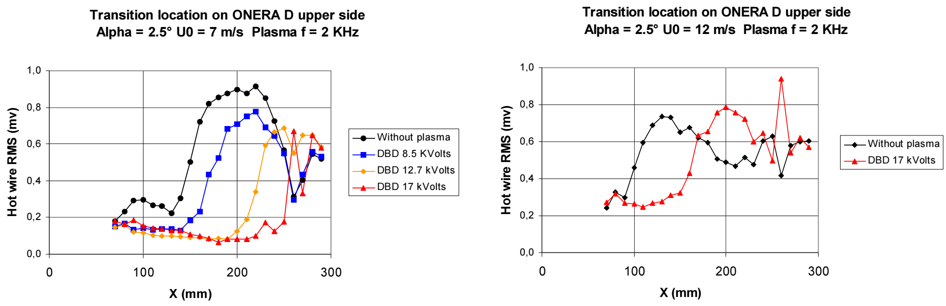


c) Separated (DBD off)



d) Re-attached (DBD on)

Figure 4. Separation re-attachment – 2D flow – Naca0015 airfoil (C = 500 mm) – PIV measurements a&b) DBD, IW = 5 m/s, U0 = 20 m/s – c&d) PSJ, V = 280 m/s, U0 = 35 m/s.



a) b)

Figure 5. Boundary Layer transition delay by DBD (30% delay). – U0 = 7 m/s and 12 m/s – 2D flow.

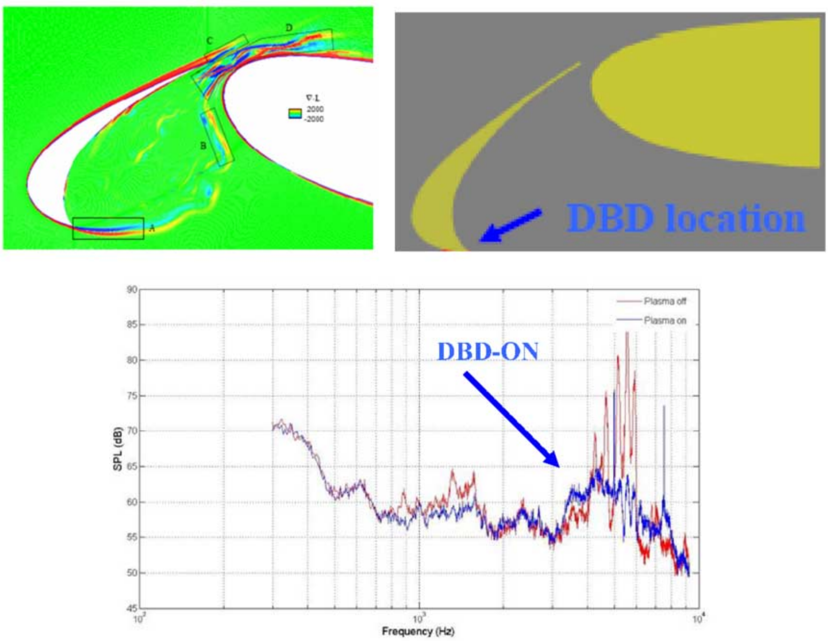


Figure 6. Slat noise control by DBD – 2D flow – U0 = 25 m/s.

3.3. High Lift Noise Control

One method for controlling high-lift noise is to use air-jet vortex generators. The slat interacting with the main element of the wing produces noise with tonal and broadband elements. It is recognised that the origin of one of the primary sources comes from the upper trailing edge of the slat. The finite thickness of the slat trailing edge produces shed vortices. The disturbances produced by the vortices are amplified and directed towards the ground due to the existence of the main element and slat. DBD plasma device should be able to induce flow momentum sufficient to be able to influence the flow in the vicinity of the slat cove (Fig. 6) [9].

4. Conclusion

In conclusion, mass flow creation or heat deposition by plasma devices can be used to add energy to a flow and improve or control it. Floating DBD, ns-DBD and PSJ actuators have been developed and some examples of aerodynamic applications with different flow control strategies adapted to plasma devices have been presented. The first results achieved at mid-term of PLASMAERO project are very encouraging. The second stage of the project seeks to show that the characteristics of these actuators can be adapted to the flows relevant to large transport aircraft.

Acknowledgments

The research leading to these results has received funding from the European Community's Seventh Framework Program FP7/2007-2013 under grant agreement n°234201. The author also acknowledges all the participants of the project, the work package and task leaders: C. Hollenstein, J.P. Boeuf, C. Gleyzes, C. Tropea, Eric Moreau, P. Leyland, F. Rogier, J. Kok, K.S. Choi, P. Molton, A. Séraudie, X. Zhang, P. Ott., P. Barricau, R. Donelli.

References

[1] J.R. Roth, Physics and phenomenology of plasma actuators for control of aeronautical flows, Journal of Physics D: Applied Physics, 40 (2007) Editorial.
[2] N. Benard, A. Mizuno and E. Moreau, J. Phys. D: Appl. Phys. 42 (2009) 235204.
[3] J. Podliński et al., 12th Int. Symp. on High Pressure Low Temp. Plasma Chemistry, 2010, pp. 74–78.
[4] P. Pechske et al., 42 Plasmadynamics and Lasers Conference, AIAA, 27–30 June 2011.
[5] T. Unfer and J.P. Boeuf, Plasma Phys. Control. Fusion 52 (2010) 124019.
[6] D. Caruana et al., AIAA-2009-1307.
[7] P. Hardy et al., Plasma, AIAA-2010-5103.
[8] A. Séraudie, 41st AIAA Fluid Dynamics Conference and Exhibit, AIAA, 27–30 June 2011.
[9] X. Luo and X. Zhang, 41st AIAA Fluid Dynamics Conference and Exhibit, AIAA, 27–30 June 2011.

About the Author

Daniel Caruana is Engineer at the Aerodyanmics and Energetics Models Department of ONERA (France)
He is PLASMAERO EU Project coordinator
ONERA – Centre Midi Pyrénées –
2, avenue Edouard Belin
F-31055 Toulouse
daniel.caruana@onera.fr
www.onera.fr

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-110

Future Fast Methods for Loads Calculations: The 'FFAST' Project

Dorian JONES and Ann GAITONDE

Abstract. The 'FFAST project' is being performed by a consortium comprising 13 members: University of Bristol, INRIA, CSIR, TU Delft, DLR, IRIAS, University of Liverpool, Politechnico di Milano, NUMECA International S.A., Optimad Engineering S.r.l., Airbus Operations Ltd, EADS-MAS and IITP. It is focused on the investigation and development of methods for accelerating the aircraft loads calculation process.

Keywords. Load calculations, field velocity method, split velocity method

1. Background

Unsteady loads calculations play an important role within much of the design and development of an aircraft, and have an impact upon the concept and detailed structural design, aerodynamic characteristics, weight, flight control system design, control surface design, performance, etc. They determine the most extreme stress levels and estimate fatigue damage and damage tolerance for a particular design. For this purpose, loads cases due to dynamic gusts and manoeuvres are applied to detailed structural models during the design phase.

The flight conditions and manoeuvres, which provide the largest aircraft loads, are not known a priori. Therefore the aerodynamic and inertial forces are calculated at a large number of conditions to give an estimate of the maximum loads, and hence stresses, that the structure of the detailed aircraft design will experience in service. Furthermore, these analyses have to be repeated every time that there is an update in the aircraft structure. Within the modern civil airframe industry, each of these loads calculation cycles requires more than 6 weeks. This long lead time, together with the multiple times this calculation procedure needs to take place, has a detrimental effect on cost and time to market. This discussion of the number of critical loads cases raises two main points.

First, the replacement of the current low fidelity models with more accurate aeroelastic simulations is attractive because of the reduced tunnel testing costs and the decreased risk of design modification later in the design process; however, the overall computational costs of the loads process must not increase.

Secondly, the new aircraft configurations that will be vital to meet future performance targets are likely to possess design envelope boundaries and therefore critical loads cases that are very different from those previously found on conventional aircraft. Engineering experience, that is currently used to reduce the number of critical loads cases without compromising air safety, cannot be extended to novel configurations.

The FFAST project is focusing on three areas of research that have been identified as offering major reductions in the total analysis cost/time.

- Faster identification of critical loads cases: minimization of the total number of requested aeroelastic analyses to some representative key-points by formalising the process and reducing dependency on engineering judgment. This will allow non-conventional configurations to be evaluated at lower risk;
- The extraction of aerodynamic and aeroelastic reduced order models (ROMs), suitable for loads analysis, from complex full order models. Such models reproduce the dominant characteristics of higher fidelity models, but at lower cost than the full order simulation;
- Reduced order model acceleration of full-order models. Full order simulations are currently too expensive for routine use, but reduced order models offer potential cost savings through convergence acceleration.

Success in each research theme may make a considerable individual contribution to the reduction of loads analysis cost. Improvements are multiplicative and the step change in analysis costs will only come about if there are simultaneous improvements in each of the three identified areas.

2. Critical Load Identification

For conventional aircraft geometries, whose response can be calculated using assumptions of linearity, engineering experience can be used to reduce the number of loads cases that must be calculated. However, for non-conventional configurations that may be required to meet future performance targets engineering judgement will not be available. Furthermore, even for conventional geometries, increasingly non-linear control systems and new manufacturing techniques mean that the assumption of linearity is becoming unacceptable. Thus it becomes clear that a more general methodology for identifying the critical cases that characterise the whole parameter space is needed. In the FFAST project the use of optimisation and design of experiments methodologies to produce a method for critical load identification is being investigated. Initially this is being developed and applied to the current design process where its efficacy can be evaluated more easily [1]. However, the methods will be extended to determine the worst case gust loads for a non-linear and non-conventional aircraft, since gusts are often the most critical load case for structural design and also are the main fatigue loading source for the majority of the structure. Gust modelling using full order CFD is not straightforward and some work has been undertaken (Fig. 1) to develop a new CFD approach that is more accurate and efficient and hence will be a good basis for the development of reduced order models [2].

3. Reduced Order Modelling

The aim of Reduced Order Modelling (ROM) is to produce a lower order model that includes all the fundamental dynamics of the full system (Fig. 2). A ROM is designed to be significantly cheaper to evaluate than a full model, offering the potential to speed up the design process while offering greater accuracy then the existing methods used in

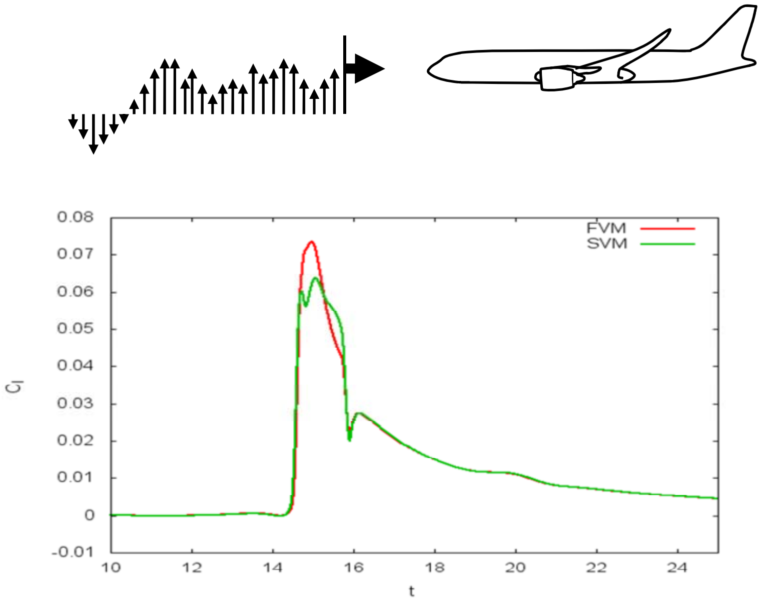


Figure 1. Vertical onset velocity profile and the response in lift coefficient to a 1-cosine gust using two different full order methods. FVM: the Field Velocity Method (also sometimes known as the disturbance velocity approach) and SVM: the Split Velocity Method.

industry. A range of aerodynamic reduced order modelling techniques having the same input/output characteristics as the full order system are being considered within the FFAST project. These methods can be used as surrogates to replace the full CFD provided acceptable accuracy and computational savings compared to full CFD can be achieved. The surrogate models for external flows that have been investigated include Proper Orthogonal Decomposition (POD) variants, Eigensystem Realisation Algorithm (ERA) based methods [3]; an extension of the non-linear harmonic balance, a ROM technique based on a Fourier decomposition of the unsteady flow components [4] and a global full aircraft aeroelastic surrogate model for use in the early stages of the design process.

4. Hybrid Methods

An alternative approach to speed up calculations is to use reduced order modelling to accelerate full order CFD rather than to replace it completely. The hybrid full order/ROM methods investigated so far have included a basis fusion method where a full order solution is advanced on a reduced basis which is supplemented as required; a zonal fusion which uses full CFD and ROMs in different regions of the domain; a multi-model space mapping approach which is similar to the multigrid approach except that it uses lower order models rather than coarser meshes to accelerate the solution and a unified solver with full order CFD [5] a non-linear structural ROM [6].

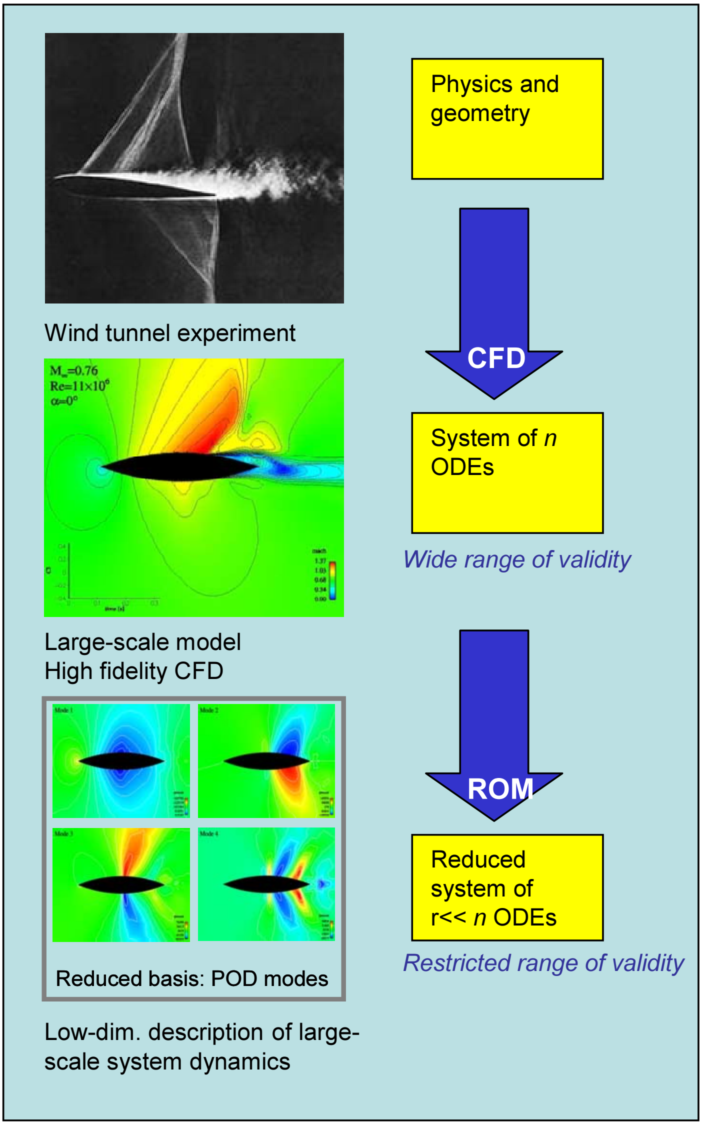


Figure 2. Concept of Reduced Order Modelling process illustrated for a biconvex aerofoil at a transonic Mach number.

5. FFAST Test Cases

In order to compare the methods implemented and developed in the FFAST project common test geometries have been developed. Due to the fact that the methods being investigated and developed are at different levels of maturity a range of test cases is needed. These consist of a full aircraft, a clean wing extracted from the aircraft and 3 aerofoil sections from points across the span (Fig. 3).

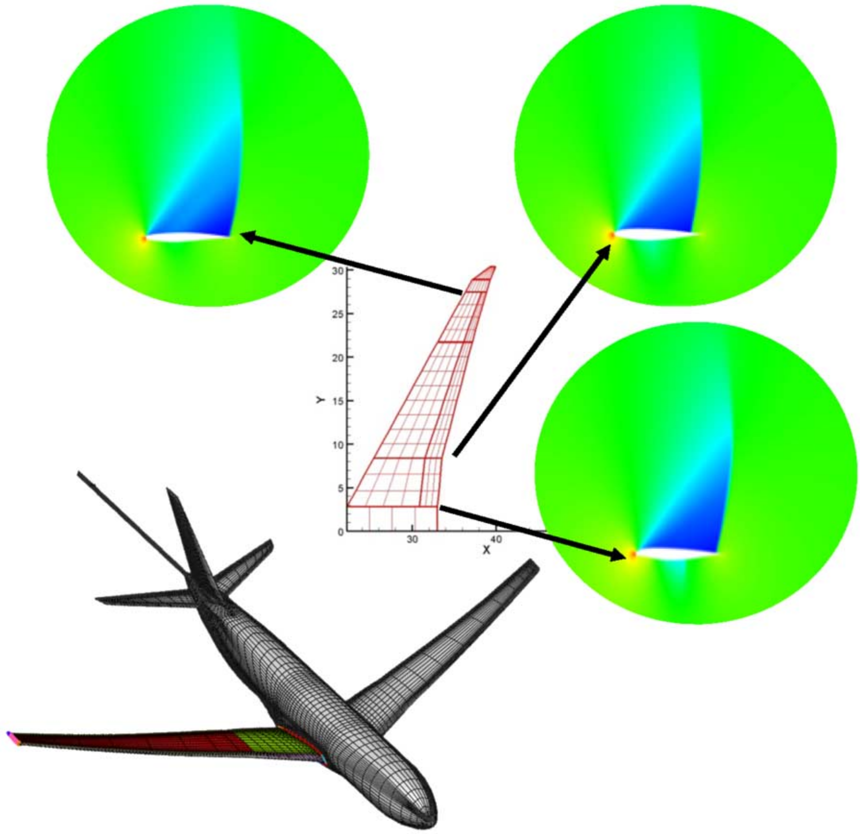


Figure 3. FFAST Test Cases from full aircraft to 2D aerofoil sections.

6. Conclusion

The FFAST objectives are to develop and assess methods to accelerate the loads process. The project is thus focused on critical load identification and reduced order modeling. All the methods have produced promising initial results. The description above is based on the status of the FFAST project after 1 year, but further work is still ongoing. The FFAST project will contribute to the goals of improving European industrial competitiveness by developing capabilities to design an aircraft concept that will have significantly lower fuel burn levels than today's best standard. Lowering aircraft fuel burn will result in reductions in CO_2 emissions that will go a significant way to meet the ACARE 2020 vision targets. In order to meet these targets the aircraft design process must evolve rapidly to allow a number of concepts to be retained and assessed from top level definition through to high levels of maturity whilst also reducing lead times. New tools and technologies are required to enable this. In this context, FFAST will provide the foundation for a new approach in the key area of rapid critical load analysis across a range of granularity and fidelity. FFAST is an upstream university led project, and as a result, the main outputs will be: new knowledge in the form of novel numerical simulation technologies and innovative approaches to the loads process; ear-

ly release software; a solution database for unsteady loads cases and recommendations in the form of written reports on a range of candidate technologies, that will guide future research investment.

References

[1] H. Khodaparast, G. Georgiou, J.E. Cooper, L. Riccobene, S. Ricci, G.A. Vio and P. Denner, Efficient Worst Case "1 – Cosine" Gust Loads Prediction, Paper IFASD-2011-48.
[2] C. Wales, D. Jones and A. Gaitonde, Simulation of Airfoil Gust Responses Using Prescribed Velocities, IFASD-2011-53.
[3] C. Wales, A. Gaitonde and D. Jones, Stabilisation of Reduced Order Models via Restarting, IFASD-2011-38.
[4] F. Debrabandere, B. Tartinville and C. Hirsch, A Staggered Method Using a Modal Approach for Fluid-Structure Interaction Computation, Paper IFASD-2011-03.
[5] T.P. Scholcz, A.H. van Zuijlen and H. Bijl, A Multi-model Incremental Adaptive Strategy to Accelerate Partitioned Fluid-Structure Algorithms using Space-Mapping, IV International Conference on Computational Methods for Coupled Problems in Science and Engineering, 2011.
[6] A.G.B. Mowat, A.G. Malan, L.H. van Zyl and J.P. Meyer, A Hybrid Finite-volume-ROM Approach to Non-Linear Aerospace Fluid-Structure Interaction Modelling, Paper IFASD-2011-08.

About the Authors

Dr. Dorian Jones and Ann Gaitonde are Senior Lecturers at the Department of Aerospace Engineering, University of Bristol
Room 1.55, Queens Building – University Walk –
BS8 1 TR, Bristol, United Kingdom
Tel.: +44 1173 315 626
Dorian.Jones@bristol.ac.uk
Ann.Gaitonde@bristol.ac.uk
www.bristol.ac.uk

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-116

Aviation Industry Roadmap to Sustainability

Thomas RÖTGER

Abstract. Based on IATA's four-pillar strategy (technology, operations, infrastructure and economic measures) a set of high-level industry goals was submitted to ICAO in 2009: average fuel efficiency improvement of 1.5% p.a. till 2020; carbon-neutral growth from 2020, net CO_2 emissions reduction by 50% in 2050 relative to 2005. Aircraft fuel efficiency measures include technologies, mainly for engines, aerodynamics and lightweight materials, which are estimated to save around 25 to 35% between 2005 and 2020. Operational and infrastructural improvements are expected to save around 10%. High potential is seen from aviation biofuels, which have been flight-tested and certified for commercial use. Sustainability standards exist that are applicable to them. However, their production costs are still high and investments into aviation biofuel production need to be encouraged by a suitable political framework.

Keywords. Climate change, technology goals, emission reduction, biojet fuels

1. Background and Objectives

Aviation contributes about 2% of all man-made CO_2 emissions, as confirmed by the United Nations Intergovernmental Panel on Climate Change (IPCC) [1]. However, global demand for air transport is expected to continue to grow by 4 to 5% per year, with related CO_2 emissions growing at a lower annual rate of about 3% thanks to continuously improved fuel efficiency. The IPCC estimates that in 2050 aviation's contribution to global man-made CO_2 emissions will be around 3% [1]. It is therefore appropriate for aviation to further decouple emissions from traffic growth.

To this end, in 2007 IATA established a four-pillar strategy [2] based on:

1. New technologies including more fuel-efficient aircraft and engine design as well as aviation biofuels;
2. More efficient flight operations;
3. Improved airspace and airport infrastructure and
4. Positive economic measures.

Based on these four pillars, all the major aviation stakeholder groups, namely airlines, airports, aircraft manufacturers and air navigation service providers agreed in 2009 on a set of collective industry goals [3], which were subsequently commended by the UN Secretary General, prior to the COP15 climate conference in Copenhagen. These high-level industry goals are:

- An average annual fuel efficiency improvement of 1.5% between 2009 and 2020;

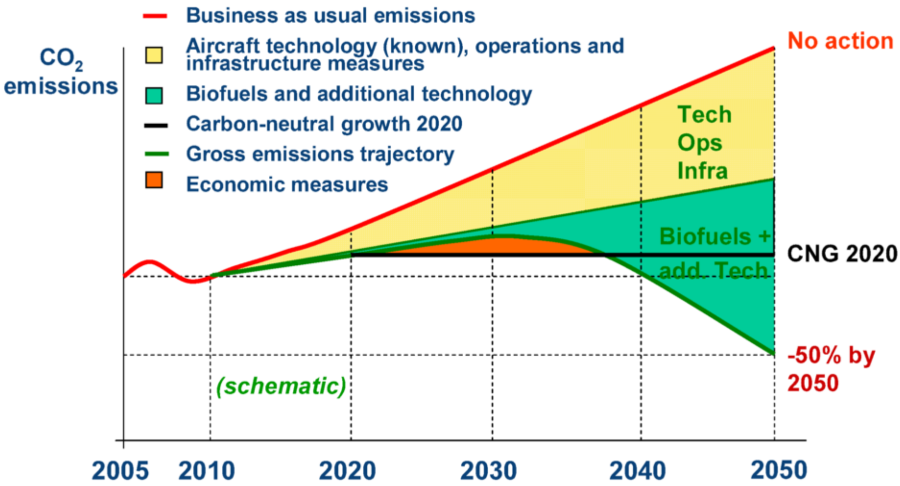


Figure 1. Roadmap to achieve the high-level industry emissions goals.

- A stabilization of net CO_2 emissions levels ("carbon-neutral growth") from 2020;
- A long-term goal of reducing net CO_2 emissions by 50% in 2050 relative to 2005.

The International Civil Aviation Organization (ICAO) recognized the carbon-neutral growth goal and set an increased fuel efficiency improvement goal of 2% p.a., which includes governmental measures beyond industry control, such as the implementation of the Single European Sky (SES / SESAR). These goals were included in the Climate Change Resolution of the 37th ICAO Assembly in October 2010 [4].

2. Emissions Reduction Roadmap

Figure 1 is a schematic illustration of a roadmap to achieve the high-level industry emissions goals with the different elements of the four-pillar strategy [5]. Compared to a "do-nothing" situation with continued traffic growth and unchanged fuel efficiency, considerable emissions reductions can be achieved by continuous improvements in aircraft and engine technology as well as optimization of operational procedures and airspace and airport infrastructure. Fuel efficiency improvement has always been one of the strongest drivers for innovation in aviation. This trend is expected to continue with unreduced effort, in line with the above fuel efficiency goals and supported by aviation R&T programmes in the EU and elsewhere.

However, to achieve carbon-neutral growth, further measures are necessary. Substantial potential is seen in the use of biofuels, which could take a strongly growing part of fuel supply in the next decades. Revolutionary new technologies in the aviation system of the future, such as alternatives to the tube-and-wing aircraft and to the current air traffic management and airport operations, are also expected to contribute substantially to achieving the 50% emissions reduction goal. It is, however, improbable that the high-level aviation industry goals will be fully achieved by direct emissions

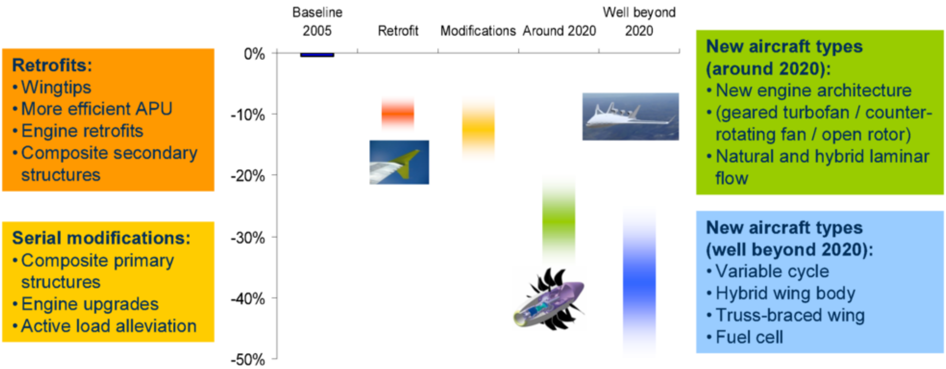


Figure 2. Estimated fuel burn reduction potential of airframe and engine technologies, from [6].

reduction alone; therefore the use of economic measures such as emissions trading and carbon offsets to close the remaining gap has not been excluded.

There are several main technological measures to improve the fuel efficiency of aircraft, principally new engine architectures (such as the geared turbofan or the open-rotor engine), aerodynamic improvements (such as laminar flow control, winglets and riblets), and the wider use of new lightweight materials for aircraft structures and cabin furnishing.

IATA, together with the German Aerospace Centre DLR and the Georgia Institute of Technology, conducted the TERESA project (TEchnology Roadmap for Environmentally Sustainable Aviation) to evaluate the potential of future fuel efficiency improvements [6]. Four time horizons were considered (Fig. 2):

– Retrofits (can be added on in-service aircraft): 7–13%;
– Serial modifications (for new aircraft of in-production types): 7–18%;
– New aircraft types around 2020 (including the new generation of single-aisles): 25–35%;
– New aircraft types far beyond 2020 (applying radical new technologies): 25–50%.

Figure 2 shows these results together with some example technologies for each group. Note that for the selected technologies in the first two groups, it is possible in principle to introduce them as retrofits or modifications within a current aircraft programme, but this does not mean that it is always economically sensible to do so. Such a decision depends, among other reasons, on the expected fuel cost savings.

Similar studies, such as the ICAO Independent Expert Study on Fuel Technology Goals [7], come to results that compare fairly well with the figures of the TERESA study. It should be noted that the reference year for both the TERESA and the ICAO study is 2005, whereas the ACARE fuel efficiency goal (50% aircraft fuel burn reduction with approximately 40% coming from airframe and engine technology) refers to a baseline in 2000, i.e. spans a longer timeframe.

Improvements in operations and infrastructure ("Pillars 2 and 3" of the industry 4-pillar strategy) are expected to add approximately another 10% of fuel savings. Operational procedures, widely under aircraft operators' own control, comprise elements such as optimized flight and fuel planning accuracy, taxiing with one engine out, wider use of ground electrical power by aircraft standing at the gate and improved mainten-

ance techniques such as regular engine washing. A large set of infrastructural improvements is being realized in the Single European Sky (SES/SESAR) [8] and its US counterpart NextGen [9], and other major ATM upgrade projects and plans are ongoing in various countries including China, India, and Japan. Various features such as required navigation performance (RNP), flex tracks and continuous descent operations (CDO) contribute to reducing fuel burn by shortening flight routes, optimizing flight profiles and avoiding hold patterns and departure queues. Obviously better air traffic management achieves higher savings in the congested European and US airspace than on routes in less congested areas that already allow relatively high fuel efficiency.

3. Aviation Biofuels

The introduction of aviation biofuels ("biojet") is seen as a major potential for aviation to reduce its CO_2 emissions. Their technical suitability has been successfully proven in a number of flight tests using commercial aircraft without any modifications [10]. Biomass-to-liquid (BtL) fuels produced by the Fischer-Tropsch process have been certified for commercial use in 2009, and the certification of hydrogenated renewable jet fuels has been completed in June 2011 [11]; applicability is expected from July 2011.

Having witnessed the mistakes made in sourcing the first generation of biofuel for road transport, leading to increased food prices and impacts on land and water use, the aviation industry is strongly focused on the sustainability of biojet fuels. In particular reduction of lifecycle greenhouse gas emissions is an important requirement. Carbon lifecycle analyses of several biofuels show emission reductions up to around 80% (e.g. camelina with 75% [12] and some lignocellulosic BtL beyond 80% [13]).

There are a number of regulations and voluntary standards applicable to biojet fuels. IATA is a Steering Board member of the Roundtable on Sustainable Biofuels, which has developed a comprehensive set of sustainability principles and criteria covering all relevant environmental, economic and societal aspects [14]. Biofuel regulations in the EU (Renewable Energy Directive, RED [15]) and US (Renewable Fuel Standard, RFS [16]), comprise sustainability requirements, which have to be met to get access to incentives. Each of these standards uses a different set of sustainability criteria. The methodologies required to demonstrate compliance with different standards are often incompatible, in particular for the calculation of greenhouse gases. For aviation as a global industry a global harmonisation of these regulations, or at least mutual recognition, would be highly desirable.

The largest remaining challenges are the need to build up production of biojet fuels at large industrial scale and to significantly reduce their production costs, which is expected to be initially about twice as high as Jet A-1. Urgent next steps for the industry are thus to attract powerful capital investors and to start the up-scaling process with demonstration plants. Synergies with the automotive biofuel sector should be developed where helpful.

Governments' influence is decisive for the success of biojet fuel implementation, in the same way as it occurred earlier in the automotive sector. A supportive political and economic framework could:

- Help bridge the price gap between biojet and Jet A-1;
- Encourage and de-risk capital investments into biojet production and promote creation of public-private partnerships;

- Intensify research and development activities on aviation biofuels;
- Provide globally harmonized biojet fuel sustainability standards and user-friendly biojet accounting methods;
- Harmonize measures in both transport and energy policy.

4. Conclusion

Aviation is the first industrial sector that has committed at the global level to ambitious short, mid and long-term goals for CO_2 emission reductions. The industry's four-pillar strategy to achieve them comprises technological innovation for aircraft and engines as well as biojet fuels, improved operations and infrastructure and complementary economic measures. An assessment of aircraft and engine technologies under development estimates a reduction of fuel burn by 25 to 35% for the new aircraft generation around 2020. Operational and infrastructural improvements are expected to yield additional savings of about 10%. Biojet fuels promise a large CO_2 reduction potential. The success of their implementation depends, however, on suitable governmental support and capital investment.

Acknowledgements

The author would like to thank Eike Stumpf and Stéphane Dufresne and their teams at DLR and Georgia Tech for their valuable work and the fruitful cooperation in the TERESA (TEchnology Roadmap for Environmentally Sustainable Aviation) project.

References

[1] IPCC Fourth Assessment Report: Climate Change 2007, R.K. Pachauri and A. Reisinger (Eds.), IPCC, Geneva, Switzerland, 2007.
[2] IATA: A global approach to reducing aviation emissions, November 2009.
[3] ICAO: A global sectoral approach for Aviation, HLM-ENV/09-WP/19, High-level meeting on international aviation and climate change, Montréal, October 2009.
[4] ICAO Resolution 17/2, A37-WP/402, 37th ICAO Assembly, Montréal, October 2010.
[5] ATAG, Beginner's Guide to Aviation Efficiency, November 2010.
[6] The IATA Technology Roadmap Report, 3rd edition, June 2009.
[7] Report of the Independent Experts on fuel burn reduction technology goals, CAEP-SG/20101-WP/11, CAEP SG Meeting, Toulouse, November 2010.
[8] SESAR JU: European Air Traffic Management Master Plan, Ed. 1, March 2009.
[9] FAA's NextGen Implementation Plan, March 2011.
[10] T.F. Rahmes et al., Sustainable Bio-Derived Synthetic Paraffinic Kerosene (Bio-SPK) Jet Fuel Flights and Engine Tests Program Results, AIAA 2009-7002, 9th ATIO Conference, September 2009, Hilton Head, South Carolina.
[11] ASTM D7566 – 11 Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons, July 2011.
[12] D.R. Shonnard, L. Williams and T.N. Kalnes, Camelina-derived jet fuel and diesel: Sustainable advanced biofuels, Environmental Progress & Sustainable Energy, Vol. 29, Issue 3, pp. 382–392, October 2010.
[13] R.W. Stratton, H.M. Wong and J.I. Hileman, Life Cycle Greenhouse Gas Emissions from Alternative Jet Fuels, PARTNER Project 20 report, version 1.2, June 2010.

[14] RSB Principles & Criteria for Sustainable Biofuel Production, RSB-STD-01-001 (Version 2.0), November 2010.
[15] Directive 2009/28/EC, Official Journal of the European Union, 5 June 2009.
[16] US Environmental Protection Agency, Regulation of Fuels and Fuel Additives: Changes to Renewable Fuel Standard Program, 40 CFR Part 80, EPA-HQ-OAR-2005-0161; FRL-9112-3, RIN 2060-A081.

About the Author

Dr. Thomas Rötger is Assistant Director, Environment Technology at the International Air Transport Association (IATA)
IATA – Route de l'Aéroport 33 – CH-1215 Genève (Switzerland)
Telephone : +41 22 770 2898
RoetgerT@iata.org
www.iata.org

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-122

REACT4C – Climate Optimised Flight Planning

Sigrun MATTHES

Abstract. The European Project REACT4C, coordinated by the Institute of Atmospheric Physics, German Aerospace Agency (DLR), addresses inefficiencies which exist in the aviation system with respect to fuel consumption and emissions by investigating the potential of climate-optimised flight routing for reducing the atmospheric impact of aviation.

Keywords. Climate impact, trajectories, climate-optimised flight routing, ATM

1. Optimising the Total Climate Impact of Flight Trajectories

Climate impact of non-CO_2 aviation emissions depend on time and the position of the aircraft, as atmospheric processes leading to climate change vary with background conditions and transport pathways within the atmosphere. Hence, a mitigation potential for climate impact exists by identifying climate-optimised aircraft trajectories.

The scope of the collaborative project REACT4C (Reducing Emissions from Aviation by Changing Trajectories for the benefit of Climate) is to expand a flight planning tool in order to be able to optimise the total climate impact of flight trajectories [1]. The scientific expertise within the interdisciplinary consortium allows to jointly set-up a modelling chain which identifies flight altitudes and flight routes that lead to reduced overall climate impact (Fig. 1). Among aviation climate impact we consider CO_2, NO_X (via ozone and methane), soot, contrail and contrail-cirrus.

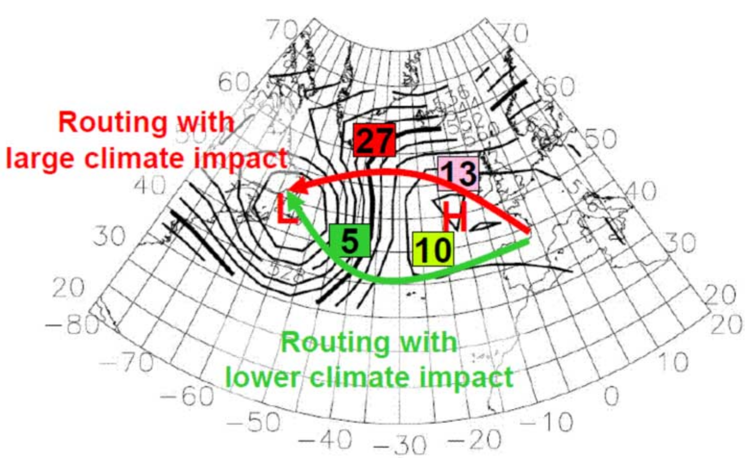


Figure 1. Schematic concept of weather based climate-optimisation (DLR Institute Atmospheric Physics).

Figure 2. Line shaped contrails and contrail cirrus forming in aircraft engine exhaust.

2. The General Concept

Starting from a particular synoptic situation (wind, temperature, humidity, background concentrations), we derive spatially and temporally resolved information on the climate impact for an emission under these specific synoptic conditions, so-called climate cost functions. These serve as interface between flight planning and climate impact. These 4d functions quantify the atmospheric climate response (sensitivity) to aviation emissions depending on space (latitude, longitude, altitude) and time of the emission. To explore the uncertainty of our procedure, this work is complemented by a scientific multi-model-assessment. Finally, potential changes in aircraft design are explored that are better suited for climate-optimised flight routing than present day aircraft.

3. The Objectives of the REACT4C Project

The main objectives of REACT4C are to explore the feasibility of adopting flight altitudes and flight routes that lead to reduced fuel consumption and emissions, and reduce the climate impact; and to estimate the overall global effect of such optimised flight routing measures in terms of climate change.

4. The Aviation Climate Impact

Aviation climate impact is composed of individual emission impacts, e.g. [2]. Direct radiative impact originates from carbon dioxide (CO_2) and black carbon (soot). Indirect impact originates from nitrogen oxides (NO_X) which form ozone (O_3) and influence methane (CH_4) life time, and from water vapour which potentially forms contrails and contrail-cirrus (Fig. 2), and from soot causing aviation induced cloudiness (AIC).

Climate impact of aviation non-CO_2 emissions depends on:

- Time and position of aircraft;
- Actual weather conditions (processes, transport pathways, temperature, humidity);
- Background concentrations.

5. Modelling Chain

The objectives of REACT4C are mainly achieved by a numerical approach, which combines atmospheric models of different complexity, air traffic management (ATM) tools for planning flight trajectories and models to calculate aircraft emissions with tools for aircraft pre-design.

- University of Reading in collaboration with UK Met Office identifies typical weather situations (classification) and characterises them, including their statistical probability.
- DLR-Institute of Atmospheric Physics jointly with CICERO, Norway calculates for each selected weather situation, radiative forcings and 4d climate cost functions for unit emissions at predefined mission location.
- Eurocontrol Experimental Centre calculates climate optimised flight trajectories. Simultaneously, the related incremental reduction in emissions and climate change is estimated.
- In a joint effort the potential total (global and annual) mitigation gain from environmental flight planning is computed, and the uncertainties in the mitigation gain from environmental flight planning are estimated.
- Atmospheric scientists from Manchester Metropolitan University (UK), DLR-Institute of Atmospheric Physics (Germany), CICERO (Norway), University of Aquila (Italy) prepare a multi-model climate impact assessment, and derive uncertainties.
- Aircraft pre-design concepts are explored by Airbus France in collaboration with DLR for climate-optimised trajectories.

An expanded flight planning tool allows optimisation with respect to e.g., minimal operational costs, or minimal climate impact.

6. Meteorological Classification

We use atmospheric indices as basis for classification of weather patterns, e.g. for the North Atlantic specifically NAO (North Atlantic Oscillation) and EA (Eastern Atlantic) oscillations. This allows to derive prevailing weather patterns and their probability to occur. For each selected weather pattern a representative (typical) real case serves as period for detailed analysis. A study to provide classification of weather patterns in the North Atlantic is currently under preparation [3]. Weather types were classified and named according to prevailing jet, e.g. strong zonal jet or strong tilted jet. An analysis of flown trajectories reveals strong influence of specific weather types (Fig. 3).

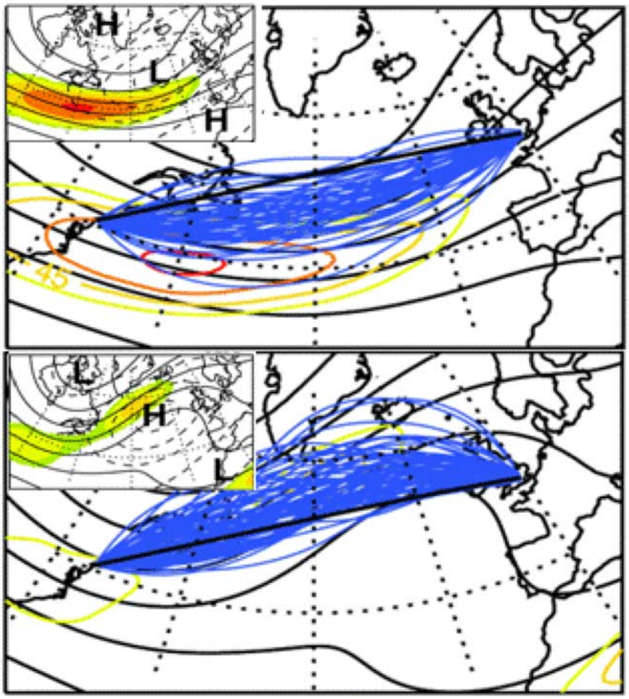


Figure 3. Weather patterns and corresponding flight tracks for strong zonal and weak tilted jet in the North Atlantic (University of Reading).

7. Climate Cost Functions

For such real weather situations we calculate 4D climate cost functions in a comprehensive global climate-chemistry-model with a Lagrangian approach, analysing the fate of aviation emissions. This allocates the corresponding climate response to an emission at a specific location and time for various weather pattern. Separate cost functions are calculated for nitrogen oxide emission, water vapour, soot, but also carbon dioxide. We quantify radiative forcing as basic variable, from which we derive standard climate metrics [4].

Background concentrations and resulting climate cost functions which show large gradients, e.g. ozone (Fig. 4), are a reliable indicator for optimisation potential with respect to flight trajectories.

8. Flight Planning Tool

As next methodological step, these climate cost functions are used as interface between climate impact model and flight planning tool (ATM). Such interface can be used for any kind of flight planning tool, irrespective of using a way-point approach or a trajectory based approach (TBO). Within our set-up we combine climate cost functions with way-point based tools which are consequently enabled to calculate corresponding climate impact for individual flight segments. For a given set of city pairs for a specific

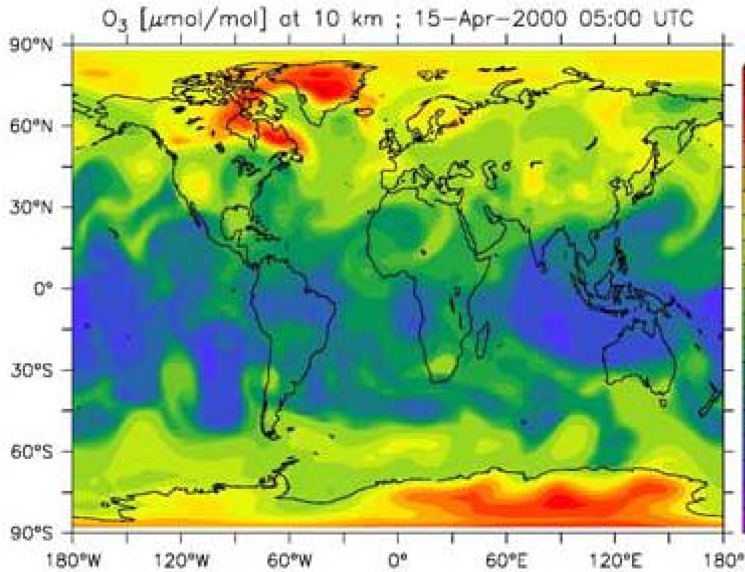


Figure 4. Background concentrations of ozone (extracted from chemistry-climate model EMAC) showing large spatial variability at cruise level (DLR Institute of Atmospheric Physics).

weather pattern the tool (SAAM) is used to analyse all available options of waypoint combinations and intersections. We calculate fuel consumption, operating costs and climate impact of each individual option simultaneously. It is then possible to identify both the minimal cost trajectory, and the minimal climate impact trajectory by means of the same flight planning tool.

9. Mitigation Gain

As final step individual optimised trajectories need to be combined to a global emission inventory, which is to be evaluated by means of chemistry-transport models with respect to its overall climate impact. This evaluation proofs the robustness of our modelling chain for climate-optimised flight planning.

10. Multimodel Estimates

To explore the uncertainty of the procedure explained above, an updated aviation emission inventory based on the CAEP/8 movement data for the year 2006 was prepared within REACT4C. Two corresponding mitigation scenarios were compiled: one shifting aircraft cruise altitudes upwards and another downwards by 2000 ft. The updated aviation climate impact estimates are calculated by means of a multimodel assessment.

Particular focus is given to reducing uncertainties for individual climate impacts of aviation, e.g. contrail cirrus. A recent update on global radiative forcing of contrail cirrus [5] is taken into account. A suite of comprehensive atmospheric models with targeted configurations is employed to derive estimates of changes in atmospheric composition.

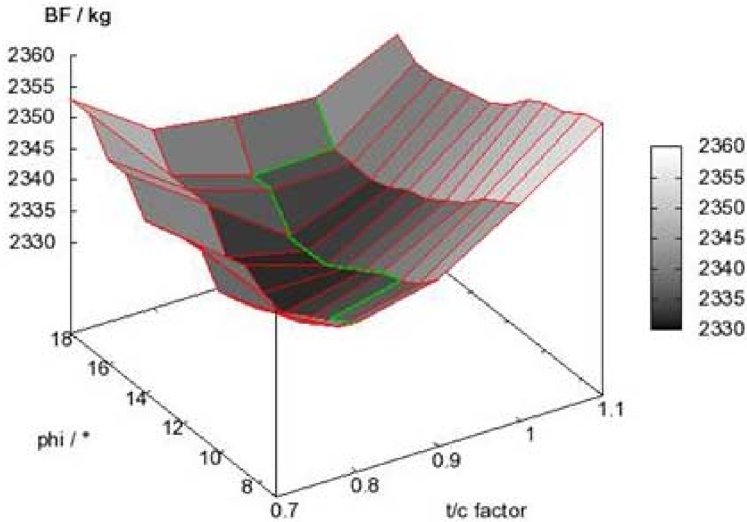


Figure 5. Pre-design optimisation concept – parametric study (Airbus).

11. Green Aircraft

For the adaptation required in aircraft pre-design, due to climate optimised trajectories (1) a systematic assessment of climate optimised flight profiles (or trajectories) is performed and (2) resulting pre-design requirements are identified. REACT4C aims to deliver fundamental concepts of aircraft pre-design that are better suited for climate-optimised flight routing, which might have the potential to enter the Clean Sky JTI in a later phase.

Having a closer look at individual aviation climate impact components quickly reveals several specific requirements. For example, minimising contrail formation might require to perform shallow (several hundred feet) step climbs and descents (to avoid shallow supersaturated regions) for individual flights. While, for example, minimising climate impact due to NO_X requires the avoidance of regions on larger (synoptic) scale, by explicitely identifying alternative tracks, which additionally exploit optimal wind conditions. For the pre-design optimisation seven degrees of freedom were analysed: wing area, engine thrust, wing aspect ratio, wing sweep, wing relative thickness, engine type, and cruise Mach number. From these, wing area and engine thrust were identified as promising optimisation parameters (Fig. 5).

For conceptual reasons we do not vary cruise Mach number in our optmisation in order to clearly distinguish between potential mitigation gain due to climate-optmised routing and any potential mitigation gain due to reduced cruise Mach number.

12. Conclusion

Within the REACT4C Consortium a number of tasks have been accomplished. Classification of meteorological situations has been successfully completed in the North Atlantic Region, with five weather classes in winter, and three classes in summer. The

modelling chain starting from individual daily meteorology, integrating climate cost functions and passing on to the flight planning tool is finalized as first set-up. An updated base case inventory and mitigation scenarios for aviation emissions were prepared based on CAEP/8 movement data and applied in a multi-model assessment. The green aircraft pre-design study identified respective study parameters, flight profiles and requirements. Active involvement of stakeholders is important for this highly interdisciplinary project and takes place in our REACT4C Expert Panel with regular meetings and thematic workshops.

For overall climate impact optimisation, individual impact needs to be considered simultaneously, specifically the impact of CO_2, NO_X, sulphate, black carbon aerosols, and contrail-cirrus. The calculation of climate-optimised flight trajectories for specific weather situations representing weather classes, allows to derive generalised recommendations for climate-optimised flight paths based on weather pattern characteristics.

Acknowledgement

This work is supported by the European Commission (FP7) under research grant AAT-233772.

The author thanks Volker Grewe and Patrick Jöckel of DLR, Institute of Atmospheric Physic, for providing scheme (Fig. 1) and ozone distribution (Fig. 3) respectively, Emma Irvine and Keith Shine of the University of Reading for making track analyses available (Fig. 3), and Christoph Blondel of Airbus France for the optimisation concept (Fig. 5). The authors gratefully acknowledge the helpful comments on the manuscript by Christine Frömming.

References

[1] Matthes et al., 2008: A novel concept for environmental flight planning, TAC-2 conference, Aachen, Germany.
[2] Lee et al., 2009: Aviation and global climate change in the 21st century, Atm. Env., 43, 3520–3537.
[3] Irvine et al., 2011: Characterizing north Atlantic weather patterns for climate optimal routing, Meteorological Applications (to be submitted).
[4] Fuglestvedt et al., 2010, Transport impacts on atmosphere and climate: Metrics, Atm. Env., 44, 4648–4677.
[5] Burkhardt and Kärcher, 2011: Global radiative forcing from contrail cirrus, Nature climate change, 1, 54–58.

About the Author

Sigrun Matthes is Atmospheric Science Researcher, REACT4C Project Coordinator and Chair of the ECATS International Association
DLR, Institute of Atmospheric Physics
Oberpfaffenhofen – D- 82334 Wessling (Germany)
Tel.: +49 8153-28-2524
Sigrun.Matthes@dlr.de
www.dlr.de

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-129

SWAFEA: A European Study on the Feasibility and Impact of the Introduction of Alternative Fuels in Aviation

Philippe NOVELLI

Abstract. Committed to taking an active role in climate change mitigation and in the promotion of secure and sustainable energy sources, the European Commission's Directorate General for Mobility and Transport initiated the SWAFEA – Sustainable Way for Alternative Fuels and Energy for Aviation – study in February 2009 to investigate the feasibility and impacts of the use of alternative fuels in aviation. Alternatives to crude oil-based kerosene are seen as an important component in the efforts to reach the target set by the European Directive for Renewable Energy (RED, [1]) to introduce 10% of renewable energy in transport by 2020. It's also an important development with view to the introduction of aviation in the ETS from 2012 [2].The study was to develop a comparative analysis of different fuels and energy-carrier options for aviation on the basis of current knowledge, and to propose a possible vision and roadmap for their deployment in order to facilitate and support future policy decisions. The SWAFEA study, which delivered its findings and recommendations in April 2011 [3],[1] encompassed all aspects of the possible introduction of alternative fuels in aviation using a highly multidisciplinary approach. This included technical, environmental, and economic assessments. The study was carried out under the leadership of the French Aerospace Research Lab ONERA, in cooperation with a consortium of twenty partners[2] bringing together European research organisations and representatives of virtually every major stakeholder in the aviation fuel chain.

Keywords. Alternative fuels, Fischer-Tropp synthetic paraffine kerosenes (FT-SPK), Hydroprocessed renewable jet (HRJ), CTL (coal), GTL (gas), BTL (biomass)

1. Candidate Alternative Fuels for Aviation

Over the last three years, the landscape of alternative fuels for aviation has quickly evolved with the approval by ASTM in 2009 of the Fischer-Tropsch synthetic paraffinic kerosenes (FT-SPK), made from coal (CTL), gas (GTL) or biomass (BTL), followed by the approval in 2011 of Hydroprocessed Renewable Jet (HRJ[3]), made from hydroprocessed vegetable oils or animal fats [4]. These products can be blended with Jet A-1 up to 50%, to produce "drop-in" fuels meaning that these fuels can be used just as if they were conventional Jet A-1, without any limitation, special handling or re-certification of aircraft.

The technical assessment performed in the frame of SWAFEA aimed at complementing these works, focused on well-established processes and final products that

clone crude-oil based kerosene molecules, by investigating possible solutions beyond these first candidate fuels.

Fuel evaluations were focused on potentially "drop-in" solutions, meaning fuels that were believed to have significant chance to be demonstrated as drop-in. Indeed, no identified not "drop-in" solution was perceived, on the basis of current knowledge, to potentially present such advantages that it could counterbalance the heavy drawbacks of being non "drop-in" both from an economic and an operational point of view.

Investigations carried out on the selected fuel types were mainly based on an experimental testing programme designed to answer key questions regarding the short to mid-term development of alternative fuels for aviation [5]. This testing programme was not intended to be an approval programme and, consequently, it included only a selection of important tests [6].

Among other results, the performed analysis showed:

- The potential interest of low blending ratio with Jet A-1 of HRJ designed with higher freezing point (while keeping the blend freezing point specification unchanged) – an higher freezing point indeed requires less processing (hydroisomerisation) which translates in higher yields and improved economic efficiency;
- The benefit with view to engine emissions of decreasing the aromatic content by increasing the blending ratio of SPK with Jet A-1 over 50% while, if many of the problems associated to aromatics content decrease could be addressed by further studies, compatibility with seals remains a critical problem, at least as long as aircraft not using "zero aromatic tolerant" seals haven't been retired from service (currently the option of synthetic aromatics is preferred);
- The potential of naphthenic compounds obtained from liquefaction (consisting mainly of cyclo-paraffins and naphteno-aromatics) as a blendstock with HRJ, additional investigation being recommended to confirm the possibility of aromatics substitution.

Emerging routes to produce hydrocarbons from sugar [8,9,10] or from lignocellulose (through an intermediate transformation in sugar) could not be assessed within SWAFEA but are certainly to be considered looking at the on-going works and at their potential interest from an economic point of view since such routes could combine relatively low cost feedstock and reduced capital cost compared to Fischer-Tropsch process.

2. The Potential for GHG Emissions Reduction

A major consideration for going to alternative fuels in aviation being the GHG emissions reduction, an important task within SWAFEA was the evaluation of the actual emissions of these new fuels. HRJ and BTL pathways were analysed for a number of feedstock. GTL was also considered as it is a mature alternative fuels for aviation that is likely to emerge to answer aviation fuel demand and provide supply diversification.

Main results are summarized in Fig. 1 for GHG global emissions ("well to wake"). All the evaluated biofuel pathways demonstrate a potential for significant GHG emissions reductions. Nevertheless, their ability to reach the RED's threshold of 60% in terms of emissions reduction depends strongly on the process, the feedstock and also the cultivation pathway which is generally the major contributor (in particular due to

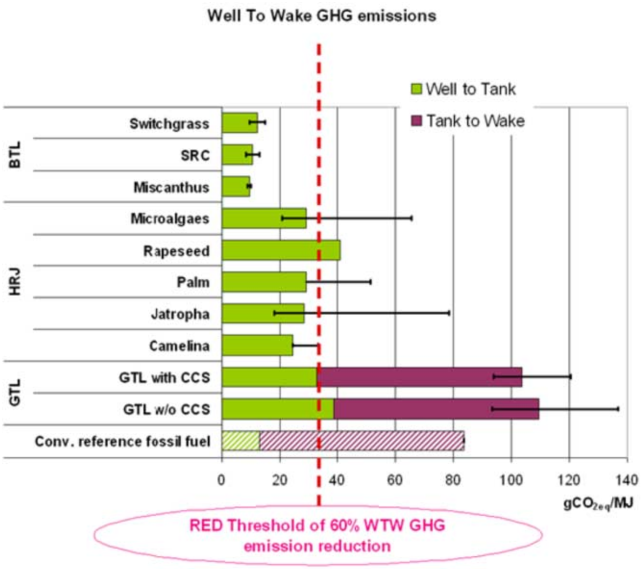


Figure 1. Short caption Results from SWAFEA life cycle assessment [11] (with no land use change). Note: reference value for kerosene is the one set by the RED.

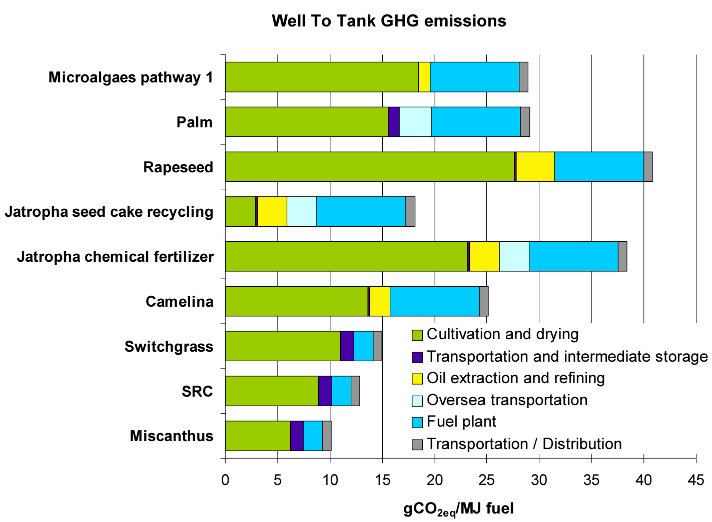


Figure 2. Illustration of contributions to biofuels life cycle emissions (with no land use change) [11].

the use of agrochemical inputs, especially N_2O) as shown in Fig. 2. The optimisation of the cultivation steps is a paramount factor for achieving GHG emissions reduction.

HRJ pathways generally produce more GHG emissions than BTL because of the use in the process of hydrogen today produced from natural gas. The evaluated oil seeds also demonstrate higher cultivation emissions than lignocellulose feedstock used for BTL. The ability of HRJ to match the RED's target finally depends on the feedstock and on the emissions associated to their cultivation.

However, like other recent studies [12], the evaluation carried out within SWAFEA shows that the contribution of land use changes may offset all benefits from a given alternative fuel if the biomass is grown on a land formerly covered by vegetation with high carbon stocks. Land use change (LUC) may easily have a dominating effect over the whole production chain[4] and should thus be carefully controlled. A current unsolved issue is that this land use change cannot always be directly observed. Indirect land use change (iLUC) may result from the displacement of cultures because of the deployment of energy crops on areas that were used for other purposes and especially for food production. No methodology is today agreed to address iLUC in LCA and iLUC is also difficult to tackle through sustainability framework for biofuel certification.

If significant emissions reductions are possible with biofuels, the analysis shows that GTL imported to Europe from a remote production facility is likely to have higher GHG emissions compared to the current EU Jet A-1 baseline. CCS can be applied, but currently, even the most complex and costly measures are unlikely to give a net reduction in carbon emissions relative to today's benchmark.

3. Alternative Fuels Atmospheric Impacts

Aviation emissions and the type of fuel used have an impact on atmospheric chemistry and on the radiative balance of the atmosphere beyond the CO_2 effect. Contrails formed by condensation of water vapour onto exhaust aerosols, including soot particles, may trigger the formation of induced cirrus clouds. Emissions of nitrogen oxides perturb the natural chemical cycles, lead to ozone production or destruction depending on latitude and altitude, and modify methane time of residence in the atmosphere [13]. These indirect effects from burning fuel at cruise altitude provide further contributions to the greenhouse effect in addition to CO_2 emissions.

From literature data and from the high pressure combustion tests performed within SWAFEA, the use of alternative fuels such as the 50% SPK blends with Jet A-1 leads to significant reduction in engine soot and SO_X emissions due to the reduced content of aromatics and sulphur. Other species are less affected and their emissions changes may depend on the combustion chamber technology (NO_X, CO, UHC) while the lower consumption associated to higher energy content of SPK is a factor for NO_X and CO_2 emissions reduction.

In addition to the positive effect on local air quality, the simulations performed in SWAFEA show that the reduced soot concentrations may affect significantly contrails properties and possibly reduce their radioactive impact in the atmosphere [14]. Additional studies on alternative contrail formation mechanisms are clearly recommended as current conclusions remain preliminary.

From the performed studies, the other impacts of alternative fuels on ozone concentrations are expected to remain modest and bellow natural ozone variability.

4. Sustainability of Alternative Fuels

Next to the assessment of GHG emissions, an analysis of the potential availability in 2050 of "traditional" biomass (agriculture, forestry and waste) was carried out within SWAFEA [14]. A proper assessment of the world agriculture production capability was

achieved. Resources from forestry and waste were added from literature review. The analysis doesn't constitute a prediction of the biomass production in 2050, but an estimate of the possible production from a "technical" point of view.

Sustainability constraints in compliance with the RED or the RSB [15] framework were enforced in the analysis (no deforestation, lands first used to secure extrapolated food demand in 2050, no negative LUC, etc.) and conservative choices were used to prevent from over-estimation. Energy crops with the highest performances, including both lignocellulose and oil seeds, were regionally selected for the production scenario.

From this assessment, agriculture appears likely to be the main potential contributor to energy biomass production, while there are significant uncertainties about long term availability of forestry resources and residues for which conservative choices were thus made.

The potential biomass availability was assessed against the biofuel demand to achieve the aspirational targets for emissions reductions. Taking into account transformation yield for BTL and HRJ, and the fact that neither hydroprocessing nor Fischer-Tropsch produce only jet fuel, it turned out that, with the performed evaluation, achieving a 50% reduction of aviation emissions in 2050 compared to 2005 would mean processing 76% of the available biomass in biofuel. This was considered as an excessive fraction. Stabilising emissions at their level of 2020 appears as more achievable target which would require to process about 52% in biofuel, preserving biomass availability for other applications. Considering the uncertainties, it is recommended that such evaluation be consolidated. Nevertheless, a conclusion is that radically more efficient biomass or processes and also revolutionary aircraft technologies should really be pursued to meet this 50% emissions reduction targets.

Achieving the foreseen development of the production in the next 40 years is also a significant challenge which requires investment in agriculture, cultivating a large amount of lands not cultivated today, and the availability of fertilizers and of manpower. Reaching a carbon neutral growth at 2020 emissions level as early as 2030 would for example request a rate of increase of the biomass production by 2030 that appears quite hard to achieve. Availability of large quantities of sustainable biomass may thus be the main bottleneck to reach industry targets.

Algae appear as particularly interesting candidates to provide additional source of biomass since they promise high yields and modest requirements on land quality, avoiding a direct competition with food. Algae potential is nevertheless still to be demonstrated, main research challenges being to confirm at large scale the high performances obtained in laboratory or pilots, and to reach competitive production costs for energy production. This is clearly an important axis of research for a wide development of biofuels.

5. Economics of Alternative Fuels

An analysis has been carried out within SWAFEA, essentially on HRJ and BTL, to evaluate how biofuels compare with conventional jet fuel and which measures could be required for their deployment [16].

The economical assessment considered the supply chain for the aviation fuel uplifted in European countries. It has been built around the industry target of halving aviation CO_2 emissions in 2050 compared to 2005, assuming no limitation on resources

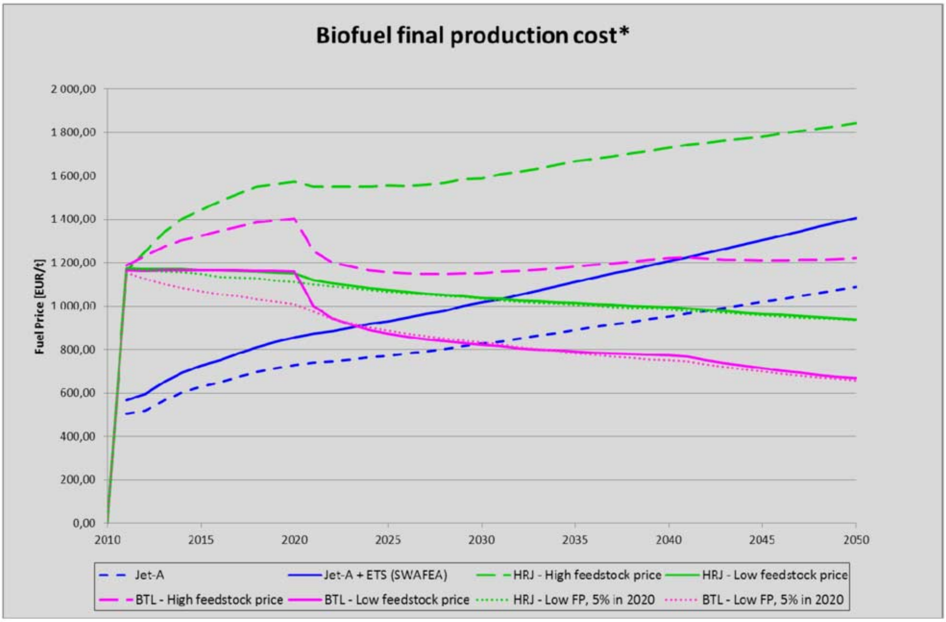


Figure 3. Biofuel final production cost (including blending cost). Reference scenario: very low penetration of biofuel by 2020. Variant: 5% penetration by 2020.

(feedstock, capital, etc.). This determines the ramp up of the industry and the "learning" effect that can be expected from the production development.

Figure 3 provides production cost simulations. They are compared to jet fuel price evolutions extrapolated from the U.S. Energy Information Agency's projections and also projections for carbon price on the basis of literature data. Cost evaluations were done for two "extreme" hypotheses for feedstock prices. The first one assumes a decrease of feedstock price thanks to learning effect and yield increase. The second one postulates an increase of feedstock price with crude oil price.

The analysis shows that neither BTL nor HRJ solutions are initially cost competitive with conventional jet fuel while in the longer term their viability depends heavily on the possibility to secure "low price" feed stock supply. Specific policy measures and incentives are thus required to initiate the deployment of biofuels.

HRJ exhibits the highest dependence on feedstock price and cost competitiveness in the medium to long term cannot be reached unless cheap and abundant sources of sustainable oils can be secured.

BTL is initially dominated by capital investment. With learning, the specific investment cost may drop and BTL fuels will eventually become cost competitive when a large number of plants have been built since the feedstock for BTL is comparably cheap and varied. The much higher required initial investment is nevertheless likely to be a significant difficulty for deployment.

Indeed, behind the production price, the development of the production capacity has also to be considered. Under the assumption that only one fuel solution is used to meet European demand, approximately 80 HRJ production plants or approximately 300 BTL production plants would be required to halve emissions in 2050.[5] This indicates

that a large and immediate technological and financial effort would be required to ramp up the production and achieve targets. The development of the production capacity is likely to be a second bottleneck to reach emissions reduction targets.

As a conclusion, specific policy measures and incentives are required to initiate the deployment of biofuels. Without further incentives, the current open ETS system, in which biofuel use is free from emissions allowances need, is not likely to trigger biofuel production start-up.

An additional important point is the strong link which exists for technical and economic reasons between the production of aviation fuel and of other products, in particular road transport fuels. The profitability of biofuels in the other transport modes is thus an important parameter of the jet biofuel business case. Competition between the two sectors has also to be managed considering the high diesel demand and attractiveness due to the existing levers of substantial duty and tax reductions.

6. Conclusions and Perspectives

Although the aviation sector has a good track record in reducing its environmental impact through efficiency gain, it is highly unlikely to reduce or even stabilise its emissions through this means alone.

Biofuels present a real potential for reducing GHG emissions, provided that the feedstock production step is well mastered. However, if at least BTL and HRJ pathways will be available in the short term to produce jet quality fuels, they face a lack of competitiveness with conventional jet fuel that is likely to hinder their development, even with the exemption of biofuels use from ETS. In addition, biomass availability and production development appear as the critical bottlenecks for biofuel ramp-up and for achieving emissions reductions targets.

Both biomass availability and economics evidence the need for more efficient processing pathways, with higher transformation yields and reduced costs, and for new sources of feed stocks.

Achieving significant emissions reduction with biofuels will need time and a determined policy, meaning also that aviation will have to offset a part of its emissions beyond 2030. Initiatives have to be decided from now to start the process and generate the learning and technological progress which is required for a faster future deployment.

Defining a low minimum goal for biofuel introduction in aviation by 2020 could be a first step on which policy measures suitable for triggering a start-up of the production could be based.

No single measure seems adapted to achieve both this production target, a significant involvement of multiple stakeholders in biofuel production and the emergence of diversified technologies. The limited profitability margin of airlines is also to be considered with view to their capacity and willingness to pay a premium for biofuel, especially in situation where policy measures could induce competition distortion. A combination of measures is probably to be preferred. In particular a global plan pushing for the emergences of a number of "end to end" projects addressing the complete production chain from feedstock to fuel could be a way to reach a minimum production target while favouring technology development and diversity along with the development of energy biomass production. Such plan could possibly be funded by the revenue of ETS auction. To complement it, the possible interest of a quota mandate policy on fuel

production could be investigated, in a "push and pull" approach that guaranties that the deployment occurs and also may offers possibilities to distribute the funding on a wider range of payers.

In any case, early deployment should definitely go with an intensification of the research on innovative processes and feedstock, and should be considered in synergy with other sectors and in particular with the automotive industry.

Endnotes

[1] SWAFEA final report is available on www.swafea.eu.

[2] SWAFEA partners: Airbus, AirFrance, Altran, Bauhaus Luftfahrt, Cerfacs, Concawe, DLR, EADS-IW, Embrarer, Erdyn, Iata, Ineris, IFPEN, Onera, Plant Research International (WUR), Rolls-Royce UK and Rolls-Royce Deutschland, Shell, Snecma, University of Sheffield.

[3] Official designation by ASTM is now Hydroprocessed Ester and Fatty Acid (HEFA).

[4] In some case this effect may be positive, for example when perennial crops are cultivated on converted grasslands.

[5] This evaluation is based on an optimum size for BTL plant around 1 Mt/y and 5 Mt/y for HRJ.

References

[1] Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources.
[2] Directive 2008/101/EC of the European Parliament and of the Council of 19 November 2008 amending Directive 2003/87/EC so as to include aviation activities in the scheme for greenhouse gas emission allowance trading within the Community.
[3] Ph. Novelli, SWAFEA final Report, SWAFEA D.9.1 report, April 2011, www.swafea.eu.
[4] ASTM D7566, Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons.
[5] C. Lewis, Technical feasibility and performance of biofuels in aviation, Aero engine analysis, SWAFEA D.3.2 report, March 2011, www.swafea.eu.
[6] Annual book of ASTM standards, D4054: Standard Specification for Qualification and Approval of New Aviation Turbine Fuels and Fuel additives.
[7] W. Weiss (1) *, H. Dulot, A. Quignard, N. Charon, M. Courtiade, Direct Coal to liquids (DCL): high quality jet fuels.
[8] http://www.amyris.com/en/markets/fuels/renewable-jet-fuel.
[9] P.G. Blommel and R.D. Cortright, Production of Conventional Liquid Fuels from Sugars, Virent Energy Systems, Inc. 2008.
[10] Ch. Ryan, Path to Cellulosic Alcohol-to-Jet, Gevo's presentation, Paris Air Show 2011.
[11] A. Prieur, L. Thellier and L. Patouiallard, Life cycle analysis report, SWAFEA D.6.2.2 report, January 2011, www.swafea.eu.
[12] R. Stratton, H.M. Wong and J.I. Hileman, Life Cycle Green House Gas Emissions from Alternative Jet Fuels, PARTNER Project 28 report, April 2020.
[13] D.S. Lee, D.W. Fahey, P.M. Forster, P.J. Newton, R.C.N. Wit, L.L. Lim, B. Owen and R. Sausen, Aviation and global climate change in the 21st century, Atmos. Environ. 3520–3537, 2009.
[14] Environmental Analysis Report, SWAFEA D.6.2 report, January 2011.
[15] RSB Principles & Criteria for Sustainable Biofuel Production, version 1.0, 12.11.2009.
[16] Christensen, Peineke, Tamboer, Hagenzieker and van Druten, Business Case & Implementation Strategies, SWAFEA D.7.1 report, March 2011.

About the Author

Philippe Novelli is Project Manager at ONERA (France)
Coordinator of the SWAFEA study
ONERA
Chemin de la Hunière
BP 80100
F-91123 Palaiseau Cedex
philippe.novelli@onera.fr
www.onera.fr

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-138

European Aviation Noise Research Network (X-NOISE)

Dominique COLLIN

Abstract. Over the last ten years, ambitious, national and regional research programmes have been initiated to support technology breakthroughs aimed at further noise reduction. Such initiatives have been established in the European Union, the United States, Japan, Canada, Brazil and the Russian Federation. The emergence of dedicated network structures has played a significant role in the elaboration and successful implementation of these various initiatives. In Europe in particular, important works are being conducted within the context of the Framework Programmes. This paper summarises the achievements of the research effort dedicated to the reduction of aviation noise as coordinated by the X-Noise network through the Coordination Actions X3-Noise (2006–2010) and X-Noise EV (2010–2014).

Keywords. Noise reduction, X-Noise network, turbomachinery noise, exhaust noise, airframe noise

1. X-NOISE: A Precursor of Networks Dedicated to Aviation Noise Reduction

The various network structures set up in the world have been used to develop and consolidate detailed research strategies addressing the high level goals set by national and regional research frameworks, establishing the conditions for more active and coordinated research covering all areas related to the International Civil Aviation Organization (ICAO) Balanced Approach. Within this framework networks provide the capability to effectively manage clusters of basic research projects as well as the transition towards further stages of technology demonstration.

The European X-Noise organisation may be considered as both a precursor and a typical example of such networks. Dedicated to the aviation noise research effort, it has developed its activities along three main directions as described below:

- The definition, coordination and assessment of research strategies aimed at meeting the 2020 ACARE noise target (average reduction of 10 dB per operation relative to the 2000 situation);
- The dissemination and communication of the Scientific research effort and technological achievements as well as issues and priorities for the future;
- The improved integration of European research community activities in the field of air transport related noise research.

2. Achievements in Noise Reduction

The ACARE Strategic Research Agenda (SRA) has established a general framework for European Aviation related research, including the definition of quantified targets for

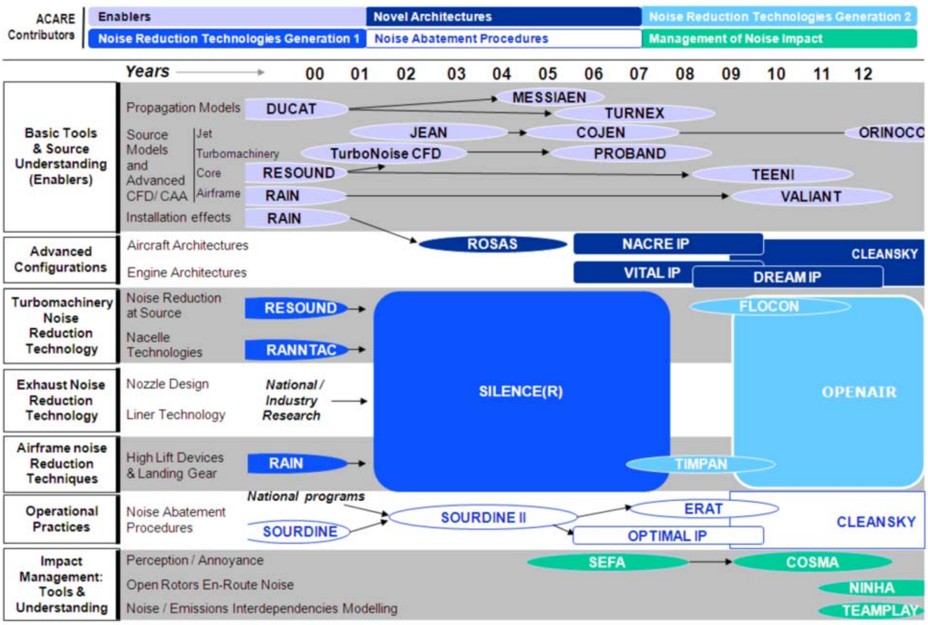


Figure 1. Roadmap of EU funded aviation noise research projects.

2020. To successfully address these objectives, a key step has been the elaboration of a detailed research strategy supported by complementary tools such as state-of-the-art assessment and gap analysis, as well as mechanisms to gather novel ideas and concepts. This has been achieved through a process involving consultation of the scientific community as well as the other major stakeholders. The scope and ambition of the resulting X-Noise network strategy and associated recommendations can be well represented by means of a projects roadmap (Fig. 1) which presents the status of EU-funded aircraft noise projects as of end 2010, addressing in effect the key research fields (also called Contributors) as identified in the ACARE SRA.

As can be seen in Fig. 1, this approach has ensured that all aspects of research were covered, in particular, activities that go beyond the development of quieter individual technologies and would support the implementation of operation and environmental practices aimed at managing the noise impact around airports, also including the modelling and understanding of Noise-Emissions interdependencies.

X3-Noise's in-depth analysis of the current achievements and Technology Readiness Level 6 prospects carried out in support of the recent AGAPE exercise has allowed a mid-term interim objective of –5 dB per operation being met by 2010 to be considered through the effort pictured in Fig. 1. Putting this status in perspective with further expectations relative to the stated ACARE Contributors, aircraft noise research effort is considered as globally on track to meet the ACARE target, but will require several breakthrough achievements before 2016. As a consequence, to maximise chances of meeting the 10dB noise reduction target, the following recommendations were expressed:

- Maintain significant effort in support of Noise Reduction Technologies Generation 2 to reach TRL6, including active techniques and addressing integration issues such as weight, performance and durability;
- Maintain support to activities on Novel Architectures, with a particular focus on Low Noise Aircraft configurations;
- Ensure successful implementation of Low Noise Operational Procedures as investigated in FP5 and FP6.

It was also pointed out that these results did not take into account the specific situation created by the emergence of the open rotor engine configuration as a serious contender when dealing with low carbon technology options. Offsetting the anticipated noise source impact associated with novel open rotor engine architectures will necessitate an aggressive approach, through dedicated research aimed at rotor blade aeroacoustic design, engine/airframe installation and flow control techniques in particular.

Furthermore, a significant aspect of research networks involves the capability to join forces and regroup with counterparts in order to address and explore wider issues.

Typical examples of such collaborations at European level include the development of a strategy aimed at "Research for a Quieter Europe" through involvement with the CALM network. The Environmental Noise Directive of 2002 focuses on a common approach to address environmental noise, to be executed at the national, regional and local levels according to the principle of shared responsibility. The associated strategic vision derived and proposed by CALM for noise research covers a wide range of areas including assessment of noise exposure and perception, health impacts of exposure to noise, noise abatement including cost-benefit aspects, new technologies and system approaches for improved noise control at source and the further development of legislative standards.

ICAO maintains a high level of activity aimed at defining future international policies and standards in the environmental area. To this end, it is developing a forward looking view by means of technology goals definition and a modelling system predicting the interdependent impacts of future policy options. The issue of noise-emissions interdependencies is also at the core of future technology efforts as absolute component performance in noise may be dependent on the trade-off positions selected with reference to CO_2 or NO_X. In this context, X3-Noise has collaborated with its counterpart network on aviation emissions (AERONET). Common brainstorming workshops have been organized to firm up a long term approach for a European framework able to manage environmental interdependencies modelling and a subsequent project (TEAMPLAY) was launched at the end of 2010.

3. Main Activities in the Dissemination Domain

X-Noise Dissemination activities do involve scientific exchanges within the European research community as well as actions aimed at international dissemination and communication.

The backbone of Scientific Exchanges is the Annual X-Noise Workshop which revolves every year around a topic relative to the research agenda. Now in place for almost 10 years, it has become a successful periodic event in Europe where the best experts in the field can present the most recent findings and the whole network community gathers and exchange information. The event has in average been attended by

70 participants, involving about 20 contributed papers each time. Regular international participation has been registered from Russia, US and Japan.

The network has also relied on a number of additional dissemination vectors such as its dedicated Public Website allowing free access to generic information on EC-funded aircraft noise projects, an EU projects publication database and all previous Scientific Workshops proceedings (www.xnoise.eu).

Another aspect of dissemination has involved communication of research achievements and prospect towards regulatory bodies. In 2007, an International Technology Seminar was organised, attended by Research Establishments and Industry from the major aircraft manufacturing countries, i.e. Brazil, Canada, EU, Japan, Russia and USA. It did feature general presentations of major national/regional aircraft noise research initiatives. A particular emphasis was put on research goals and their definition process. The European participants later contributed to the material presented to the ICAO CAEP Independent Experts Panel at the occasion of the Noise Technology Review held in September 2008. Similarly, early in 2011, a new event has been organized to prepare for the second CAEP Noise Technology Review scheduled at the end of 2011.

4. Integration of Research Community

Thanks to the various individual projects and the networking efforts carried out over the last ten years, the European Aircraft Noise Research Community has now reached a critical mass. As of the middle of FP7, more than 150 different organisations had participated in at least one noise project proposal over the last 4 EU research framework programmes. Three priorities have then driven the network activities in this area:

- Ensure better coordination of expertise at national level, so that value-added contributions for EU projects are more clearly identified, around a common set of well disseminated priorities and objectives, also leading to a better exploitation of national funding around similar priorities;
- Ensure better identification and exploitation of national upstream research into the more comprehensive EU projects, such as Integrated (Level 2) Projects;
- Favour development of local networks, with a particular emphasis on new EU member states, in order to foster participation in future projects, with a particular focus on SMEs.

To this end, a network of National Focal Points (NFPs) has been established together with appropriate resources tailored to the specific national situations. Within the NFP system, the initial phase of network development focused on identifying potential participants, mapping local expertise as related to stated priorities in aircraft noise research at EU level (ACARE scope) and establishing the network in the national context. Workshops and information sessions have been organized by the Focal Points, national homepages have been established. Furthermore, representatives of CIS, South America and Mediterranean regions have also joined the network to strengthen links and develop opportunities for further international cooperation.

5. Future Perspectives

X3-Noise has now been superseded by the new X-Noise EV Coordination Action which will extend the network activities further as described in the conceptual "3-Pillar" approach shown below (Fig. 2).

This extended scope should strengthen the technology effort and simultaneously ensure that the "Management of Noise Impact" contributor is effectively implemented, having in mind further recommendations expressed in support of the AGAPE assessment, namely:

- Consolidate European predictive capability to evaluate the impacts of aircraft and rotorcraft noise on communities, including environmental interdependencies;
- Support improved understanding and modelling of community impact and overall psycho acoustic annoyance;
- Promote a harmonised policy framework on land use practices and mitigation options as well as develop clear indicators to assess progress made in their effective implementation.

More generally, as lasting organizations beyond the limited timeframe of individual projects, research networks ensure a much needed structural continuity aimed at longer term strategies. Examples of multidisciplinary European network collaboration have also served to emphasize the interest of such structures to address complex environmental issues at strategic level. Similarly, a concerted approach benefiting from networks support could create more international cooperation opportunities for research aimed at reducing aviation environmental impact.

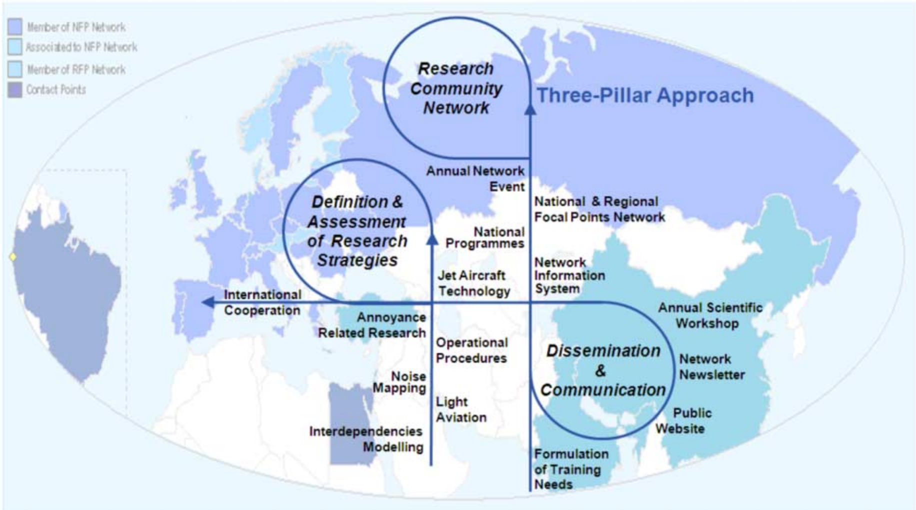


Figure 2. X-NOISE 3-Pillar approach, key network features and geographic involvement.

About the Author

Dominique Collin is Research Engineer at SAFRAN/Snecma – X-Noise Coordinator
SAFRAN/Snecma – Centre de Villaroche
F-77550 Moissy Cramayel
dominique.collin@snecma.fr
www.snecma.fr
www.xnoise.eu

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-144

Validation and Improvement of Airframe Noise Prediction Tools

Christophe SCHRAM and Lilla KOLOSZÁR

Abstract. The European project named VALIANT – VALidation and Improvement of Airframe Noise prediction Tools – is a Collaborative Research Project addressing the external noise challenges raised by the development of green aircraft. It focuses on broadband airframe noise (AFN) by tackling both landing gears and high lift devices, which are the two main contributors to AFN of an aircraft at approach. The complexity and diversity of broadband turbulent airframe noise sources make that prediction and subsequent reduction with present numerical tools extremely challenging and far from mature.

Keywords. Airframe noise prediction, aeroacoustics, Eddy simulations

Since the 1950's, the increase in population density around airports and the increase in number of aircraft flights have given rise to much greater intrusion of aircraft noise on community life. Community noise is cited today as a major problem to be solved by the aircraft transport industry to improve the environment around airports and to allow the current growth of passenger travel to continue.

The objective is to contribute to the ACARE strategic goal of reducing the external noise by 10 EPNdB per operation in 2020, taking 2001 as the baseline. European aeronautical industry has committed to meet this extremely demanding challenge. Amongst various other important aspects, the fulfillment of the ACARE objectives involves the improvement of accurate and fast prediction techniques to enable virtual prototyping and shorten development cycles. The VALIANT consortium is very much aware of the fact that a project dealing with a real airframe with slat, flap and landing gear integrated in a unique complex geometry would not permit the answering of questions concerning the maturity and validation of the numerical methods. Indeed, such assemblies would require prohibitive computations as well as wind tunnel testing, which are incompatible with the development, systematic comparison and experimental validation of high-accuracy numerical tools. This knowledge can be accumulated only by studying isolated generic configurations (slat, flap, landing gear, etc.). Moreover, previous and currently running research programs dealing with AFN, such as RAIN, SILENCE(R), AWIATOR, TIMPAN, CLEANSKY and OPENAIR, study realistic rather than generic configurations, with a clear focus on noise reduction technologies at a realistic scale. In contrast, VALIANT is aiming to validate/improve noise prediction tools and represents a very complementary contribution towards the ACARE goals.

The following specific flow configurations representing the basic mechanisms of AFN generated by the most relevant elements of a real aircraft have been selected in

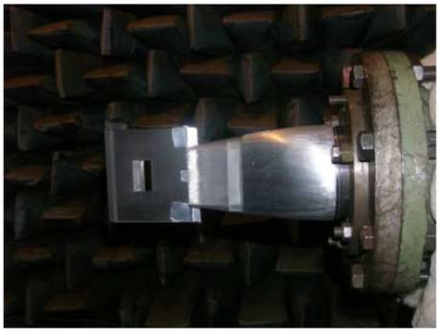


Figure 1. The gap model installed in the anechoic chamber AK-2 of TsAGI.

VALIANT for a thorough investigation aimed at validating and improving the broadband AFN predictive tools:

- Turbulent flow over a gap;
- Flow past airfoil with flap;
- Flow past airfoil with slat;
- Flow past two-struts.

The first configuration reflects the main features of the flow field found in any aircraft retractable device, the second and the third cases are more specifically representative of the high-lift wing devices, and the last configuration includes interactions that take place in landing gears. Thus these four generic flows actually cover the most important sources of AFN generated by a real aircraft and therefore their study provides a sufficient basis for evaluation and improvement of the Computational Aeroacoustics (CAA) tools aimed at predicting AFN.

For each of the four aforementioned basic configurations the main technical objectives are:

– To generate a detailed, accurate experimental database on broadband noise associated with the configuration including the turbulent flow sources causing the noise;
– To validate and improve CAA tools for prediction of the corresponding type of broadband AFN and generate a detailed numerical database.

The use of generic configurations permits the establishment of very complete and accurate experimental databases that will be used for the validation of the prediction tools, which is an essential step towards their improvement. The first half of the project has therefore focused on measurements, particularly to obtain the necessary data for validating the simulations. Since numerical simulations, especially Large Eddy Simulations (LES) and Detached Eddy Simulations (DES) are very sensitive to boundary conditions, some measurements to provide these inputs had to be conducted in the early stages of the project to permit a timely start of the simulation work.

All planned measurements related to the gap test case were performed by TsAGI (Fig. 1). Based on the inflow parameters provided by these measurements the numerical partners were able to start their state-of-the-art simulations on this geometry.

Until now, mainly aerodynamic results have been obtained. IMM performed simulations using the DES and Delayed DES (DDES) approaches, while TUB used just the

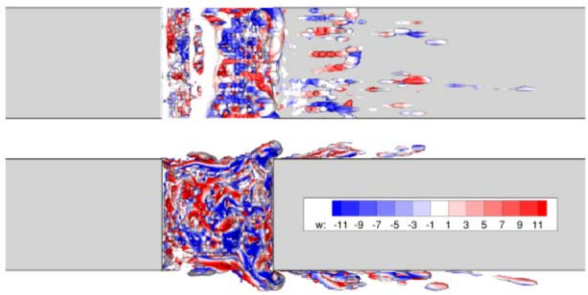


Figure 2. Vortical structures captured in the gap configuration, indicated by λ2-isosurface coloured with spanwise velocity component.

DDES model (Fig. 2). Based on these first simulations further improvements of the computational methods were identified.

The wing-flap simulations were also started as soon as the necessary boundary condition input data were made available. These measurements were done in the anechoic wind tunnel of ECL. During the two measurement campaigns detailed acoustic and aerodynamic data were collected by ECL and ONERA (wall-pressure, hot-wire, microphone array, single microphone measurements) [1,3]. In the second half of the project, VKI will perform PIV and acoustic beamforming measurements of the same wing-flap arrangement (with span doubled with respect to the ECL mock-up) in its L1 wind tunnel.

The first numerical simulations of the wing-flap were performed, based on the hot-wire data collected by ECL over the wing. DLR used a RANS based noise prediction technique where it is possible to separate the regions of sound production. Using this technique they found that the wing is mainly radiating low-frequency noise, while the high-frequency content is more due to the presence of the flap, the gap between them contributing to the whole range of radiated frequencies (Fig. 3).

All the other partners involved in this configuration use transient flow simulation, either LES or Improved DDES (IDDES) in order to resolve the noise source region around the bodies. The generation of synthetic turbulence at the inflow was found to be a crucial point for achieving meaningful results. Within the framework of VALIANT, NTS [2] dedicates special effort to this problem (Fig. 4).

The definition of the wing-slat case required a preliminary CFD and optimisation step. ONERA performed a numerical optimisation of the 2D airfoil-slat configuration having a retracted wing-slat chord of 0.3 m. The objective was to obtain a mean flow and a distribution of noise sources in the slat region representative of a conventional high-lift wing with deployed flap and slat at an incidence of 4° while minimising the overall lift and deviation of the wind tunnel open-jet. The optimised airfoil is a 2-element wing with a nominal incidence of 18°. Detailed numerical simulations including the whole test section revealed that the measurements should be conducted with an angle of attack 27° in order to reproduce the free stream conditions of 18°. The measurements conducted at ECL confirmed that an angle of attack of 25° permits the targeted pressure distribution in the slat area to be produced. As in the previous test case, the measurements are done both at ECL and VKI. For CFD (Figs 5 and 6), VKI, ONERA, NTS and NUMECA conducted unsteady flow simulations based on LES-like

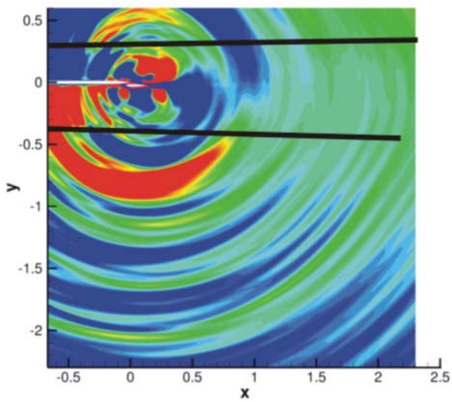


Figure 3. Superposition of individual snapshots of the sound pressure for different sources, for the wing-flap test case.

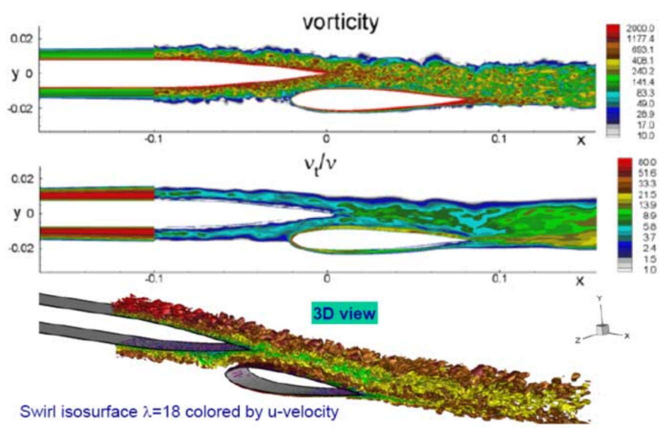


Figure 4. Visualisation of E-IDDES solution for the wing-flap case: snapshots of vorticity and eddy viscosity in XY-plane and 3D view of swirl iso-surface.

methods. DLR used a stochastic approach of turbulence reconstruction from steady RANS computation as described before.

The twin-strut configuration was measured in the small anechoic wind tunnel (Fig. 7) of NLR who performed both far-field and microphone array measurements to determine the noise directionality and the source localisation for different regimes of speeds and angles of attack of the twin-strut alignment. Besides these acoustic measurements NLR obtained pressure data on the surfaces of the struts and VKI performed PIV measurements. TUB has performed CFD simulations (using a DDES technique) and still needs to complete the aeroacoustic analysis based on the FW-H formulation. CIMNE has performed preliminary 2D CFD simulations (using a VMS technique) on the two original test cases.

Two formulations have been compared, the so-called algebraic sub-grid scale method and the orthogonal sub-scale stabilisation method. The inhomogeneous Helmholtz equation will be solved to compute the acoustic pressure in the far-field. IMM uses a hybrid DES method for the numerical computation of the compressible viscous flow

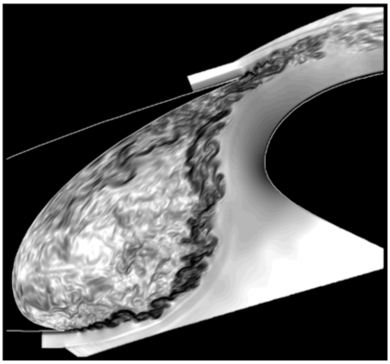


Figure 5. Instantaneous Schlieren-like view in the slat cove region.

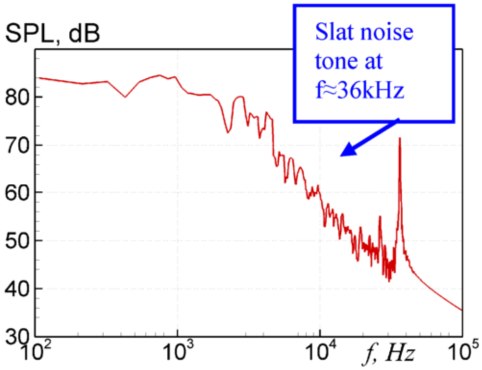


Figure 6. Power Spectral Density of pressure, wing-slat configuration.

Figure 7. KAT test section with airfoil section (white) and microphone array.

(Fig. 8) whiles the aeroacoustic analysis will be based on the FW-H formulation. NUMECA has performed LES simulations for the two original test cases and still needs to complete the aeroacoustic analysis based on the FW-H formulation.

The second half of the project will focus on completing the experimental campaigns (PIV in particular), and on developing and implementing improved numerical

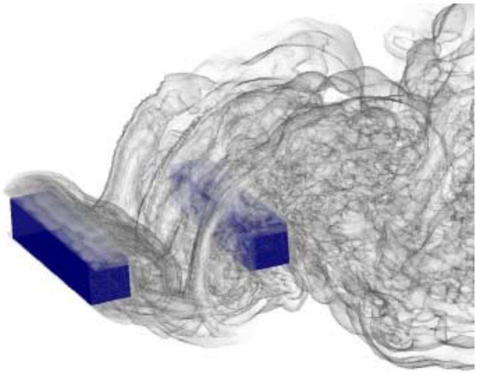


Figure 8. Instantaneous flow field in mid-span plane and in 3D, visualisation is based on turbulent viscosity (SA model).

and analytical simulation tools. Once all the improvements are implemented a series of second-pass simulations will be conducted with the upgraded methods. In terms of dissemination and exploitation of the results, two Lecture Series (March 2012 and 2013) will be organised by VKI to share the experiences and results obtained throughout the project. In addition to these important events, scientists participating in other active EC projects (OPENAIR, CLEANSKY) have been contacted with a view to the organisation of joint workshops, where the best suited methods for AFN prediction and their potential for integration into industrial processes for airframe noise reduction will be presented.

References

[1] B. Lemoine, M. Roger and I. Legriffon, Aeroacoustics of a Model Non-Lifting Wing-Flap System in a Parallel Flow, 17th AIAA/CEAS Aeroacoustics Conference (32nd AIAA Aeroacoustics Conference) 05–08 June 2011, Portland, Oregon.

[2] M. Shur, P.R. Spalart, M. Strelets and A. Travin, A Rapid and Accurate Switch from RANS to LES in Boundary Layers Using an Overlap Region, Flow Turbulence Combust (2011) 86:179–206.

[3] M. Terracol, E. Manoha and B. Lemoine, Investigation of the unsteady flow and noise sources generation in a slat cove: hybrid zonal RANS/LES simulation and dedicated experiment, AIAA Paper 2011-3203, 41st AIAA Fluid Dynamics Conference and Exhibit, Honolulu, Hawaii, 27–30 Jun 2011.

About the Authors

Dr. Christophe Schram is Assistant Professor at the von Karman Institute of Fluid Dynamics (Belgium)
schram@vki.be

Dr. Lilla Koloszar is Ph.D. student in the same Institute
koloszar@vki.ac.be

von Karman Institute of Fluid Dynamics
Ch. De Waterloo 72
Rhode-St-Genese
B-1640 Belgium
+32 2 3599611
www.vki.ac.be

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-150

Structure of the Combustion in a Trapped Vortex Combustor

Joseph BURGUBURU, Gilles CABOT, Michel CAZALENS and Bruno RENOU

Abstract. Due to continuous efforts through past and ongoing European projects, lean combustion by means of internally staged injectors now appears to be the promising technology for obtaining the required emission reductions compatible with a sustainable growth of aviation transport. The European project "TECC-AE" – Technologies Enhancement for Clean Combustion in Aero-Engines – addresses a number of fundamental issues. To look even after ahead and to overcome the complexity issues inherent to stages lean combustors, TECC-AE also focuses on the design of an innovative lean combustor concept and on the development of a compact Ultra Low NO_X (ULN) injection system.

Keywords. Clean combustion, combustor chamber, flame, particle image velocimetry, trapped vortex combustor

1. Background

The ACARE organisation (Advisory Council for Aeronautics Research in Europe) set the objective of a 80% decrease in NOx emissions by 2020 for aircraft engines. To reach this objective, several European projects have been carried out. The TECC-AE project (Technologies enhancement for clean combustion in aero-engines) is one of them.

The main objective of this project is to provide tools and technologies to develop an overall staged lean combustion technology capable to fulfill the required reduction. However, to reduce NOx emissions, it is necessary to reduce the flame temperature. It means generally to burn in lean conditions. In actual swirl stabilized combustion, lean conditions tend to provoke combustion instabilities which could be very harmful for the safety of the whole engine. New ways of flame stabilization have to been found.

A part of this project focuses on the study of a new combustor architecture. This one is based on the concept of a flame stabilized by the hot product recirculation localized in a cavity. This concept is called Trapped Vortex Combustor (TVC).

TVC concepts have been studied since 1993 [1–4] and showed promising results in term of flame stability and lean blow out limit. The first studied burner was cavity only fueled. In the second generation, both the main and the cavity flows were fueled. Moreover the flame stabilization was enhanced by flame-holders [4].

The objective of the experimental device built in collaboration with Snecma and settled in the CORIA laboratory, is to better understand the mechanism of the flame stabilization in this new configuration.

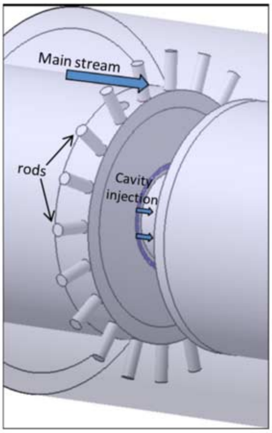


Figure 1. Description of the combustion chamber: The cavity in which takes place the pilot flame, the rods and the main annular stream in which burns the main flame.

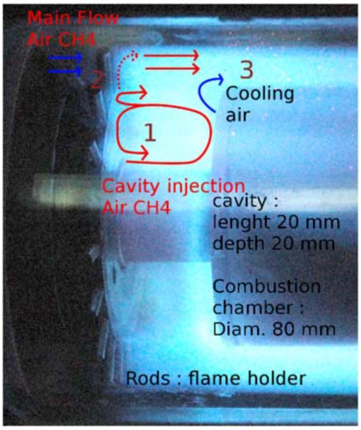


Figure 2. Picture of a stabilized flame in the transparent TVC burner: (1) flame inside cavity, (2) Main flow, pressure drop just behind rods, (3) main flame stabilization.

2. Theoritical Flame Stabilization Mechanism

The "rich" flame located inside the cavity generates a continuous source of burn products and a source of highly reactive radicals. These highly reactive elements go from the cavity to the main stream thanks the presence of rods immerged in the main stream (Fig. 1). They generate a wake zone downstream, characterized by a law velocity zone and a law pressure zone. The pressure drop sucks up the radicals from the cavity to the main stream and provides a continuous source of burn gases enabling the stabilization of the main lean flame (Fig. 2).

3. The Combustor Chamber

The combustion chamber is axis-symmetric and totally transparent. The diameter of the annular main stream is equal to 80 mm and its thickness is equal to 10 mm. This stream is fed by a lean air/methane mixture. The cavity width can be varied from 18 mm to 25 mm and its depth is fixed to 20 mm. The cavity air methane mixture is injected with an annular slot of 1 mm height at the bottom of the cavity. 20 rods of 3 mm diameter are radially placed in the main stream, just upstream the cavity (Fig. 1). They act as flame holders. Cooling air is injected on the downstream face of the cavity (Fig. 2). In this first study, the burner is fuelled with methane. The mas flow rates of the different inlets of fuel and air are piloted by a set of thermal mass flow rate controllers.

4. Measurement Techniques

Three measurements have been carried out simultaneously in reactive conditions: the flame chemiluminescence, the velocity field and the dynamic pressure.

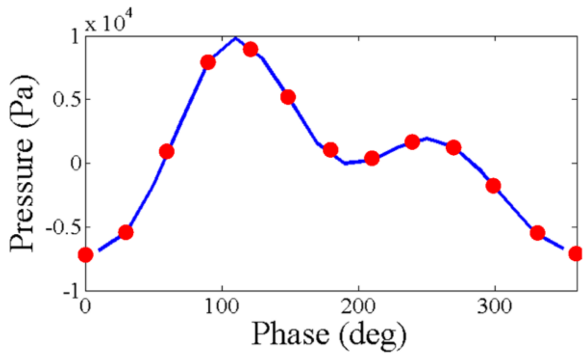


Figure 3. Evolution of the pressure inside the combustion chamber during a cycle. Phased locked measurement positions are noticed by red circles.

The 2D velocity map is measured thanks to the Particle Image Velocimetry technique (PIV). These measurements have been done with two Nd:Yag lasers (532 nm) pulsed to a 4 Hz frequency and with a double exposure camera delayed at 10µs. The cavity and main flows are seeded by 1 µm zircon particles.

The light emitted by the flame is an indicator of the flame chemistry (chemiluminescence). Then the collection of the spontaneous emission of CH* radical thanks to an ICCD camera and to an appropriate spectral filter inform us of the position and the intensity of the combustion reaction The two cameras are focused in the same plane and triggered at the same 4 Hz rate.

The dynamic pressure in the combustion chamber informs us of the cyclic instabilities of flame. The pressure signal is continuously acquired during the measurements and each couple velocity/CH* field is temporally referenced to the pressure signal. The temporal analysis of the pressure signal allows sorting of images as function of the temporal phase. And then for each phase, an average and a root.mean.square (r.m.s.) can be calculated. This permits the reconstruction of the phase matched of simultaneously mean velocity and mean intensity reaction maps. The 0 deg phase corresponds to the minimal of the pressure signal (Fig. 3).

Velocity measurements have been done into two planes along the axial direction: In the middle plane located between two rods (hereafter MP), and in the plane of a rod (hereafter RP).

5. Results

The Main flame structure has been measured for the reference case. The velocity of the main flow equals 8 m/s for an equivalence ratio of 0.85. The velocity of the cooling air equals 6 m/s. The velocity of the cavity injection equals 8 m/s for an equivalence ratio of 3.

The mean flow topology (Fig. 4) obtained in reactive conditions presents these characteristics: in both planes (MP and RP) a vortex is present in the inner part of the cavity. Its upper tangential direction is opposite to the main flow direction. Therefore, a second despun vortex is present which makes the velocity continuity with the main flow. In the RP, thanks to the depression generated by the rods, a part of the vortex

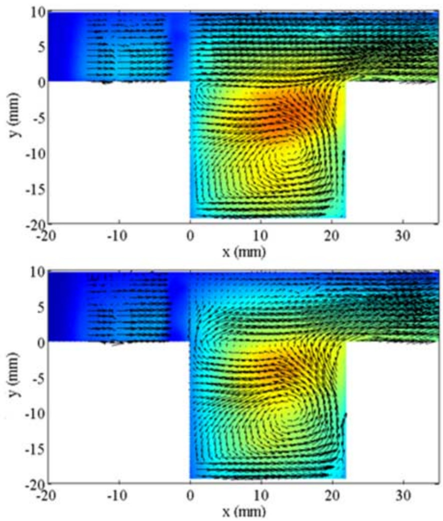


Figure 4. Mean velocity field colored by mean CH* emissions. Top: Middle Plan. Bottom: Rod Plan. The velocity field in the rod plane highlights the importance of gas suction.

takes place in the main flow. In the middle plane without the depression generated by the rod, the second vortex is queasily inexistent. In both plane, close to the cooling air injection, the mean flow highlights the leakage of the cavity flow into the main flow. The frequency of this phenomenon equals 150 Hz. Moreover, the presence of harmonics in the pressure fluctuations (150 Hz, 300 Hz, 450 Hz) confirms the strong coupling between the acoustic of the combustion chamber and the flame fluctuations.

The phased locked flow fields and CH* measurements provide more information on the flame dynamic.

The minimum of the combustion intensity is start line for the description of the cycle, the cycle the main flow is queasily extinguished (290 deg. see Fig. 5) and the flame is located inside the cavity. Due to the high equivalence ratio inside the cavity, and speed of the injected flow, the flame takes place after the mixing between the cavity flow and the cooling air flow. Residuals of the main flame of the previous cycle are convected downstream, at the exit of the main channel. A small amount of CH radicals in the wake of the rod: The depression generated by the rods sucks the burn gases into the main stream as shows the velocity field close to the rod.

The intensity the combustion increases (290–350 deg. see Fig. 5). The burn gases sucked and the low velocity zone behind the rod initiates the combustion in the wake of the cylinder, close to the cavity. The intensity of the combustion in the main stream increases and combustion gets to the outer part of the combustion chamber.

Moreover, the acoustic plays an important role on the overall flow velocity. The amplitude of the pressure fluctuations is about 1.5 *104 Pa (Fig. 3). Consequently, the amplitude of the velocity fluctuations equals about 20 m/s. On the whole combustor, the axial velocity decreases by amplitude of 20 m/s simultaneously confirming the strong influence of acoustic on the axial velocity field. The velocity inside the main stream decreases below zero (110–180 deg) down to a minimum value (–6 m/s, 145 deg).

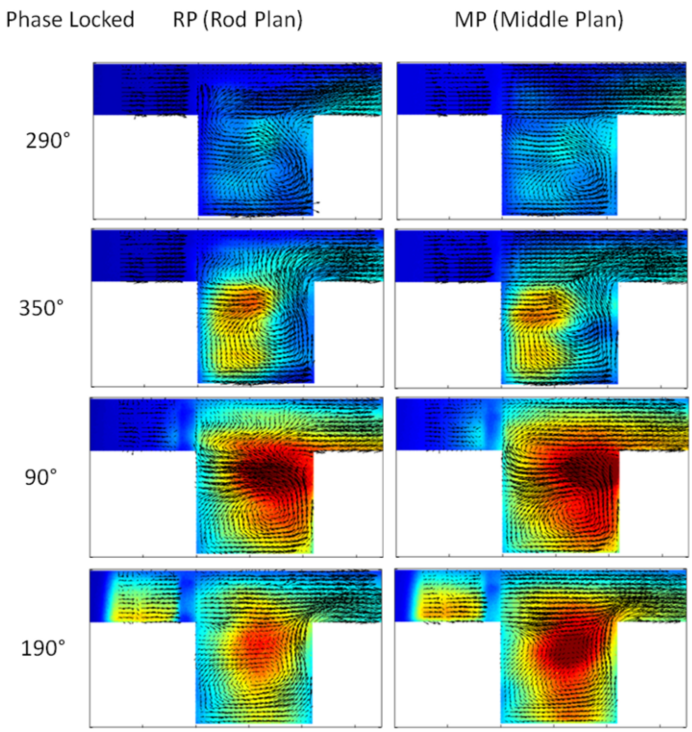


Figure 5. Phased locked velocity field colored by CH* emissions at different instants: Left in the Rod Plan, right, between two rods (Middle Plan).

With the law and decreasing incoming air fuel mixture velocity, the flame propagates in the upstream direction (90 deg, Fig. 5) in the main channel and the axial velocity becomes negative (100 deg). This flame propagation in the upstream direction is enhanced by the cavity dynamic. Thermal extension inside the cavity makes the burn products go fast into the main stream in the upstream direction. However, thermal expansion dilates the burnt gas of the main stream in the downstream direction. .The second vortex is still present and the cavity is aerodynamically closed (90–170 deg). Then the cavity empties (190 deg) in its downstream part (Fig. 5).

Meanwhile, the main flame front propagates more than 20 mm upstream in the main channel. Then, the acoustic velocity fluctuation increases (150 deg), becomes positive (172 deg), convecting downstream the main flame out of the channel progressively. The main flow composed by burnt gases, penetrates into the upper part of the cavity. It highly stretches the flame in the cavity and reduces its intensity. Combustion mainly occurs in the downstream part of the cavity, up to the downstream air injection, close to the wall.

The increase of the main flow velocity increases the suction of the burnt gases into the main stream behind the rods: though, the main stream flame front has been convected downstream the rods, CH* signal is present and its intensity increases (290 deg). The cycle is over.

6. Conclusion

This trapped vortex combustor confirms the mechanism of the flame stabilization. However, the flame stabilization is greatly influenced by the velocity fluctuations generated by the acoustic flow field. The acoustic frequency of the combustion chamber fits to the dynamic response of the flame. The amplitude of the acoustic velocity fluctuations strongly destabilizes the combustion. The numerical simulations validated from this study shows that the flame becomes stable for a higher main flow rate.

References

[1] K.Y. Hsu, L.P. Goss, D.D. Trump and W.M. Roquemore, 1995. Performance of a Trapped Vortex Combustor, in: AIAA (Ed.), 33rd AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV, USA.
[2] K.Y. Hsu and G.J. Sturgess, 1997. Entrainment of mainstream flow in a trapped-vortex combustor in: AIAA (Ed.), 35th Aerospace Sciences Meeting & Exhibit, Reno, NV.
[3] K.Y. Hsu, L.P. Goss and W.M. Roquemore, 1998. Characteristics of a trapped-vortex combustor. Journal of Propul-sion and Power 14:57–65.
[4] W.M. Roquemore, D.T. Shouse, D. Burrus, A. Johnson, C. Clayton, V.R. Katta, G.J. Sturgess, K.-Y. Vihinen, 2001. Trapped Vortex Combustor Concept for Gas Turbine Engines, in: AIAA (Ed.), 39th AIAA Aerospace Sciences Meeting & Exhibit, Reno, NV.

About the Authors

Joseph Burguburu
CORIA UMR 6614
Snecma – Avenue de l'Université – BP 8
F-76801 Saint-Etienne de Rouvray
Tel.: +33 (0)2 32 95 98 53
joseph.burguburu@coria.fr

Dr. Gilles Cabot
Same address as above
Tel.: +33(0)2 32 95 97 67
gilles.cabot@coria.fr

Professor Bruno Renou
Same address as above
Tel.: +33(0)2 32 95 98 54
bruno.renou@coria.fr

Dr. Michel Cazalens
Snecma – Rond-Point René Ravaud – Réau
F-77550 Moissy-Cramayel
Tel.: +33 (0)1 60 59 76 95
Michel.cazalens@coria.fr

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-156

TIMECOP-AE: Towards Innovative Methods for Combustion Predictions in Aero-Engines

Thomas LEDERLIN

Abstract. The aim of the FP6 TIMECOP-AE project (2006–2010) was to improve the necessary combustion prediction methods that enable the development of practical advanced combustion systems for future engines, with reduced emission levels and fuel consumption. Predictive tools are required to be able to reduce NOx emissions, to decrease the development time and costs of new combustion systems and to improve the operability of lean-burn combustion systems. Most promising approaches to satisfy future emission levels regulations are based on lean combustion technology. However, lean combustion compromises combustor operability, including ignition, altitude re-light, pull-away, weak extinction performance and thermo-acoustic instability behaviour. Therefore it is of prime importance to evaluate the behaviour of the flame during these transient phases in the design stage and modelling tools are required. Without these tools the development of advanced combustion systems relies on many costly and time consuming rig tests. The high-fidelity simulations proposed in TIMECOP-AE are therefore a way to increase our competitiveness.

Keywords. Large Eddy simulation (LES), ignition kernel, visualisation techniques

1. The Large Eddy Simulation Approach

During the last years big advances have been made in the field of reactive Large Eddy Simulation (LES) with gaseous fuels. This approach gives promising results with respect to turbulence modelling and can be used to model unsteady processes. Within the framework of TIMECOP-AE, the LES tools have gained a new critical capability: modelling of the liquid fuel combustion process for conventional and low-emission combustors, over a wide range of operating conditions. The operating conditions include the above-mentioned transient phenomena, such as ignition or extinction. The developments achieved in the simulation tools are concerned with models for turbulence, chemistry, turbulence-chemistry interactions, and liquid spray models. The methods and models developed within TIMECOP have been evaluated against high quality validation data issued from several validation test-rigs, from academic burners designed to validate a specific model up to a generic combustor, representative of an aero-engine combustor (Fig. 1).

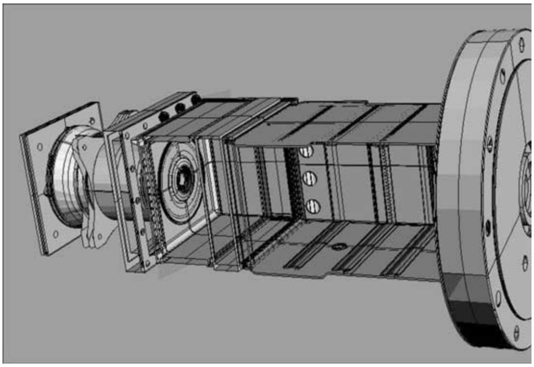


Figure 1. Generic combustor experimental model.

To reach the main objective of advancing LES methods into two-phase flows for gas turbine applications, TIMECOP was divided into 4 work packages and the technical activity distributed as follows:

- Development of models and study of fundamental issues, handled by work package 1;
- Production of experimental data for validation, handled by work package 2;
- Implementation of 2-phase capability in numerical solvers and validation calculations, handled by work package 3;
- Application of new simulation tools to industrial configurations, handled by work package 4.

2. TIMECOP at a Glance

23 institutions from 8 European countries constituted the TIMECOP consortium:

- Universities: University of Cambridge (UK), Technische Universität Darmstadt (GER), Karlsruher Institut für Technologie (GER), Technische Universiteit Eindhoven (NED), Imperial College (UK), Loughborough University (UK), Czestochowa University of Technology (POL), University of Rome (IT), Ecole Centrale Paris (FR);
- Research centres: CERFACS (FR), ONERA (FR), DLR (GER), IMFT (FR), CNRS (FR), ICEHT (GR), IFPEN (FR);
- Industries: Turbomeca (FR), Rolls-Royce Deutschland (GER), Rolls-Royce plc (UK), MTU (GER), SNECMA (FR), AVIO (IT).

The scientific production of the project is summarized here:

- 7 test-rigs;
- 18 CFD codes or modules;
- 94 technical deliverables validated;
- 41 publications produced.

3. The Scientific Content

3.1. Work Package 1 – Fundamentals

Within this work package, numerical models for two-phase flow, chemistry and ignition have been developed, improved evaluated and tested. Both Eulerian and Lagrangian two-phase models have been considered, and the performances of the two approaches have been compared. Chemistry models have been developed for application to LES. Approaches are based on the Flamelet Generated Manifold method, the Conditional Closure Model, the Field PDF method, and the Computational Singular Perturbation method. Furthermore, a specific spark ignition model has been developed. The models have been implemented in numerical solvers and exploited by industrial partners.

3.2. Work Package 2 – Validation Experiments

There are a number of factors that still prevent full utilisation of such sophisticated simulation methods, especially for spray flames, by industry. The need to improve the reactive LES capability is closely dependent on availability of accurate, comprehensive diagnostic measurement data to be used for validation. WP2 focused on development and application of advanced diagnostic techniques on geometries and flow problems ranging from very well defined, easy-to-characterise, academic test cases to industrial test cases. The former tests were used to support model development, the latter to validate models in presence of complex geometries and ambiguity in boundary conditions.

A wide range of advanced visualization and diagnostic techniques (e.g. PIV, PTV, PDA, LDA, IMI, PLIF, OH* chemiluminescence, Mie scattering) have been used and often tested to the limit of their capabilities (Fig. 2).

Attention has been paid to analyse a range of operating conditions, going from altitude relight up to cruise. Both reactive and inert experiments have been carried out. A good combination of single- and two-phase flow experiments has been conducted. The data collected has been then used to both define boundary conditions and validate LES predictions. Important aspects of evaporation, turbulence-chemistry interaction, droplet transport and droplet combustion have been investigated. Notwithstanding the obvious challenges posed by application of these advanced techniques, which often have gone through their own development process within TIMECOP-AE, the objectives of producing a comprehensive matrix of test cases for validation of LES methods has been achieved as per plan.

In summary, the significant achievement of WP2 has been to stretch the capability of existing diagnostic techniques and so provide valuable LES validation data used elsewhere in TIMECOP-AE. In particular, demonstration has been provided that advanced laser diagnostic methods can be directly used on industrial geometries and can produce a wealth of information on the aerothermal behaviour of aero-engine combustors.

3.3. Work Package 3 – Numerical Validation and Implementation of Fundamentals

The aim of this work package was to integrate the fundamental models into the advanced CFD methods, in order to obtain the 2-phase reactive CFD capability and resolve the intrinsic unsteady behaviour of turbulent flows. To ensure the proper imple-

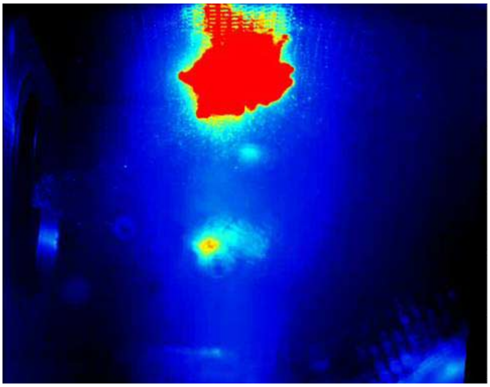


Figure 2. Experimental visualization of an ignition kernel.

mentation of these new models, validations were first performed on academic experiments. Once validated, the advanced CFD methods were ready to be tested on complex 3D geometry experiments.

All the tasks defined in the Description of Work of the TIMECOP project have produced state-of-the-art scientific results and contributions in multiple scientific publications in international conferences and journals. Such a prolific production is the result of the developments and validations of multiple LES strategies to handle two-phase reacting flows not only from a theoretical point of view but also for industry-like configurations. Despite minor adjustments all the tasks with strong links with WP4 (Exploitation) have provided new industrial tools with great potential as illustrated by the industrial partners.

3.4. Work Package 4 – Exploitation

LES of reactive two-phase flow is the next evolution in CFD methodologies applied to the conception of aeronautical engines. It should complement and eventually replace existing RANS conception techniques. The justification of this evolution resides in the fact that engine performances and transient phases are not predictable with the only use of RANS. Some examples are flight relight, combustion instabilities, ignition and lean blow-off prediction, etc. Also RANS is very depending on turbulence modelling and there is no general turbulence model adapted to any geometry or engine operation circumstance. The basis principle of LES makes this technique naturally adapted to complex turbulent flows, such as those encountered in aeronautical combustors (Fig. 3).

TIMECOP-AE has greatly helped introduce the LES tools into the industrial environment for aero-engine design. All industrial partners have computed one of the configurations that were experimentally tested in WP2. The results proposed have clearly shown that performing LES of two-phase reactive flows in an industrial context is feasible. Previous to TIMECOP-AE project, LES was mainly used by researchers without or with a weak link with the aeronautical industry. Several research projects (PRECCINSTA, ICLEAC, MOLECULES) have helped industrials evaluate and understand the interest to adopt such LES tools to improve the conception process. However, only gaseous-fuel combustion simulations had been applied to industrial configurations. TIMECOP-AE has brought 2-phase flow modelling, which is an essential feature in

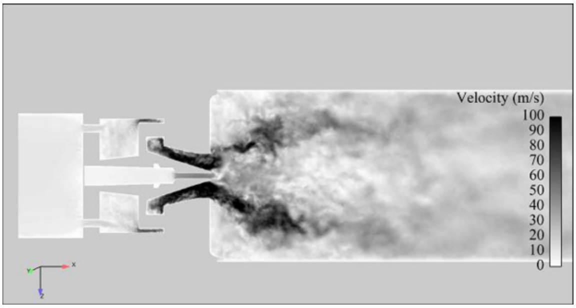


Figure 3. LES velocity field in a model aero-engine combustor.

combustion simulation, into the industrial applications. LES technique still remains to be improved in terms of robustness and computational time consumption to be routinely integrated in the industrial conception cycles. However, all aero-engine manufacturers in TIMECOP consortium have tested it, by adapting owned CFD tools to LES, by adopting research tools modified to fit the industrial needs or by testing commercially-available tools.

4. Conclusion

TIMECOP-AE has helped consolidate the requirements that LES tools should satisfy to be integrated in the aero-engine industry conception process. Models required by industry needs have been developed by the research partners of this project, integrated in the industrial tools and then evaluated by the industrials against academic and real combustor engine geometries. The industrial LES related methodologies have started to be developed by each company. The research effort in this field should be continued; noticeably to obtain faster solvers to fit the conception timeline of aeronautical engines and to improve the models developed in TIMECOP.

About the Author

Dr. Thomas Lederlin is Combustion Research Engineer at the Methods Department of Turbomeca S.A. Turbomeca – BP 17
F-64511 Bordes Cedex
Tel.: +33(0)5 59 12 50 65
thomas.lederlin@turbomeca.fr

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-161

Towards Flutter-Free Turbomachinery Blades

Damian M. VOGT and Torsten H. FRANSSON

Abstract. The Royal Institute of Technology, Sweden, is leading an EU FP7 project called "FUTURE" involving a consortium of 25 partners from industry, research institutes and academia. Flutter is and remains one of the key limiting phenomena when designing next generation of green aircraft and engines. Precisely, the main objective of the FUTURE research programme is to ensure that the phenomenon of flutter is not harming the mechanical integrity of tomorrow's aircraft engines. By advancing the state-of-the-art in flutter prediction capabilities and design rules, FUTURE will lead to benefits in terms of decreased development costs, reduced weight and fuel consumption, as well as increased ability to efficiently manage flutter problems on engines at service. The focus of FUTURE is put on two primary areas of turbo-machines, in which flutter is observed: low-pressure compressors and low-pressure turbines.

Keywords. Flutter-free blades, turbomachinery, low-pressure compressors, low-pressure turbines

1. Introduction

The propulsion of civil and military aircrafts is today almost exclusively based on turbomachinery-based engines, which is primarily due to their unprecedented power density. Turbomachines have progressively evolved since the middle of the last century and key advances have been made in increasing reliability, availability and environmental friendliness. Today's aircraft engines consume on an average 12% less fuel than their late 1990-ies counterparts [1] and are thanks to this much "greener". Environmentally friendly aircraft engines are light, powerful, silent and produce low emissions of greenhouse gases and nitride oxides. This is achieved by having an efficient propulsion concept such as a high bypass ratio turbofan and by having an efficient power generation cycle. Below, a number of trends are listed that contribute to making an aircraft engine "greener":

- Increased component efficiency;
- Reduced component counts (i.e. fewer stages, fewer blades);
- Reduced weight of components;
- Increased cycle and propulsion efficiency.

In the light of these trends, there are limits for how "green" and aircraft engine can become presently using traditional cycles. Component efficiencies are already very high and major improvements are therefore hard to realize. Cycles can still be made more efficient, but the primary limitation is the available technology, which to a large degree still is under development. Reducing engine overall weight by reduced compo-

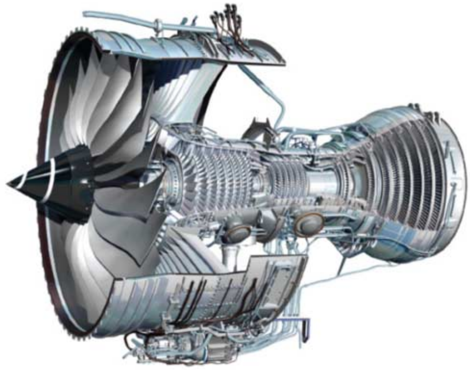


Figure 1. A modern aircraft engine (picture courtesy of Rolls-Royce).

nent count and reduced weight of components is one of the key trends in developing new aircraft engines. All these developments must however be made without compromising safety and last but not least affordability. Of many phenomena affecting the mechanical integrity of turbomachines, flutter is probably the most severe, as it can lead to the disintegration of components in very short time.

2. The Phenomenon of Flutter

Flutter denotes a self-excited and self-sustained phenomenon that is due to the interaction of fluid and structure [2]. In other words, an air flow past a structure can excite the structure by itself without any external input. Unless properly damped, flutter rapidly leads to excessive vibration amplitudes that literally can rip components apart or have them failing due to High-Cycle Fatigue (HCF).

Given its severity, the phenomenon of flutter has gained attention already early in the development of turbomachines, even before these were used in aircraft propulsion. It has early been recognized that both the ratio of mass between the structure and the surrounding fluid as well as the vibration frequency of the structure play an important role for the flutter susceptibility of an object [2,3]. In this sense, long and slender components are more prone to flutter than short and sturdy ones.

Modern aircraft engines feature such kinds of blades in the low-pressure parts of the system, i.e. the fan and the low-pressure compressor on one hand and the low-pressure turbine on the other hand (Fig. 1). It is thus primarily these components that are of concern with respect to the flutter phenomenon.

3. Designing for Flutter Safety

Whereas in previous years the design of turbomachinery in general and the design of components for flutter safety were largely based on empirical methods, the use of Computational Fluid Dynamics (CFD) tools is nowadays regarded as industry standard. CFD methods allow analyzing a flow field in three-dimensional (3D) and very detailed manner based on flow models that are implemented in a numerical manner and solved on a mesh of finely distributed grid points. The models can be used to analyze the

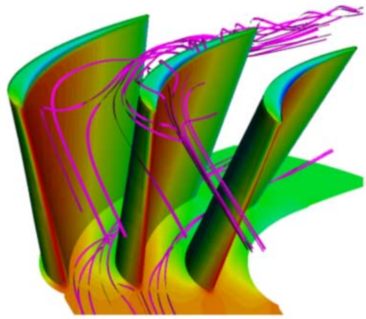


Figure 2. Typical output from a 3D CFD analysis on a turbine blade row.

steady flow, i.e. the flow in which there is no variation of flow quantities over time, or the unsteady flow.

Unsteady analyses typically feature computational efforts that are of an order of magnitude greater than steady analyses. It is thereby the user, who chooses whether a steady or an unsteady analysis is appropriate. Furthermore, the extent of the analysis domain must be set such that the phenomena of interest are captured with the employed model. Commonly, CFD analyses span over a part of an aircraft engine only (one or several stages) rather than the entire engine. Typical outputs from CFD analyses include pressure distributions, identification and quantification of losses, power transfer and streamlines (Fig. 2).

When designing for flutter safety, the analyses usually include a structural and an aerodynamic part given the interdisciplinary character of the investigated phenomenon. In the structural part, one or several vibration mode shapes are determined using Finite Element Modeling (FEM). Using CFD, it is thereafter analyzed, how the flow responds to a certain vibration mode shape. This response can be of the following type:

– The flow responds in a way in which the energy from the vibration is damped. The specialists refer to this as “positive damping”. This is always a preferred situation;
– The flow responds in a way in which the vibration is augmented, which is then referred to as “negative damping”. Negative damping can lead to flutter, if the amount of negative damping from the flow exceeds the amount of positive (structural) damping of the setup.

The inherent complexity when designing for flutter safety is the fact that the least stable modes are not known a priori [5]. Flutter analyses therefore always imply that a large number of modes are analyzed and consequently, such analyses are very time consuming and tedious. Having these analyses being part of the turbomachinery design process in an early stage presents a challenging balance between adequate accuracy of the numerical tools employed and the computational costs associated. State-of-the-art nowadays is that flutter can be predicted at a fair degree of accuracy (refs). Uncovering a flutter problem at a later stage in the design process may be extremely costly. El-Aini et al. [6] report that whereas 90% of all possible High-Cycle Fatigue (HCF) occurrences are uncovered during engine design, the remaining 10% stand for one third of total engine development costs.

4. Description of the "FUTURE" Project

In the light of the aforementioned challenges associated with flutter in turbomachines, the Royal Institute of Technology (KTH), Sweden, is leading an EU FP7 funded project called FUTURE (www.future-project.eu) involving 25 partners from industry, research institutes and academia. Within the FUTURE project, a combined experimental and numerical effort is undertaken, such as to increase the prediction accuracy of turbomachinery flutter predictions. As such, the FUTURE project will provide European aero engine module manufacturers with improved design tools that significantly reduce both the need for costly redesigns and the risk for late flutter events. The focus of the project is put on the two primary areas of turbomachines, in which flutter is observed as are i) low-pressure compressors and ii) low-pressure turbines.

The challenge when doing validation of numerical tools for flutter predictions lies in the complexity of the involved phenomenon. Whereas full engine tests represent the reality in the best way, they are of less suited in generating validation data. There are many reasons for this ranging from the possibility to acquire pure and undisturbed data, controllability of the operating point, instrumentation and data acquisition to name a few. Instead, it is more beneficial to use simplified setups, in which engine-typical flow conditions are achieved while the instrumentation is tailored such as to measure the involved phenomena in an accurate manner.

In the FUTURE project, a number of different aerodynamic test facilities are used as are:

- Non-rotating compressor cascade rig with controlled oscillation of blades;
- Non-rotating turbine cascade rig with controlled oscillation of blades;
- Rotating compressor rig (1 ½ stage);
- Rotating turbine rig (1 stage).

Whereas the cascade test facilities open up for detailed instrumentation and an intimate assessment of the involved unsteady aerodynamic phenomena, the rotating counterparts provide a more engine typical environment and produce validation data with having both aerodynamic and structural phenomena interacting.

The compressor test object (Fig. 3) has been designed such that negative aerodynamic damping (i.e. flutter) can be achieved depending on the compressor operating point.

The test object is of blisk type (i.e. integral disk with blades) and is operated at high rotational speed (up to 20,000 rpm). The rotating compressor tests are performed in a facility at the Technical University in Darmstadt, Germany. In these tests, the vibration of the various blades is measured using tip-timing technology with optical probes. Furthermore, the unsteady blade surface pressure is measured on various blades such as to conclude back on local aerodynamic damping parameters. The structural properties of the test object are characterized in a spin rig at the École Centrale de Lyon, France, where piezoelectric excitation of the structure is used. In addition, a non-rotating cascade counterpart is operated at the École Polytechnique Fédérale de Lausanne, Switzerland. The cascade features extensive instrumentation of the blades, such that detailed validation data can be acquired.

On the turbine side, a low-pressure turbine (LPT) profile has been designed that is typical for present and future generations of aircraft engines (Fig. 4).

Figure 3. Compressor test object.

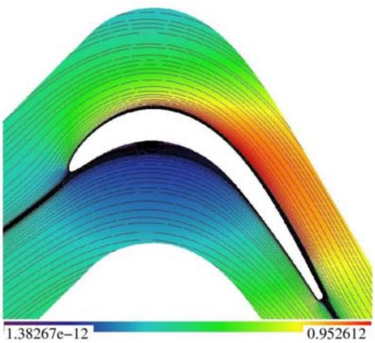


Figure 4. Turbine test object.

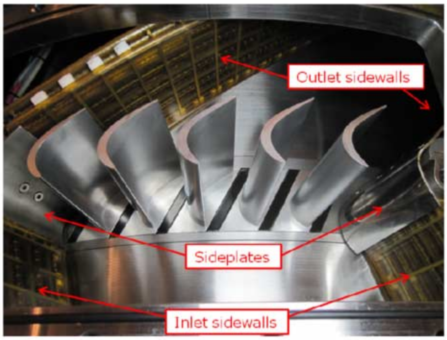


Figure 5. Turbine sector cascade test rig.

The test object is of bladed-disk type (i.e. disk with separate blades) and is operated at low rotational speed typical for modern high bypass-ratio turbofans (around 2,500 rpm). The rotating turbine tests are performed at the Centro de Tecnologías Aeronáuticas, Spain. Two test objects are investigated, that differ in the mechanical setup. Similar to the compressor, the blade vibration amplitudes are measured using tip timing technique. The structural properties of the test object are characterized in a spin rig at AVIO, Italy, where magnetic excitation of the structure is used. In addition, a non-rotating cascade counterpart is operated at the Royal Institute of Technology, Sweden (Fig. 5).

Again, these tests are used to gain detailed insight into the unsteady aerodynamics during blade oscillation.

In parallel to the experimental activities, a comprehensive part of numerical analyses are performed by the various partners. On one hand, these analyses have been performed when designing the test objects and characterizing the experiments. An extensive set of pre-test predictions have been performed by various partners using their own flutter analysis best practices such as to have a comparison of the results upfront the experiments [7]. The comparisons indicate a spread of predicted aerodynamic damping in the order of magnitude of 100% (Fig. 6).

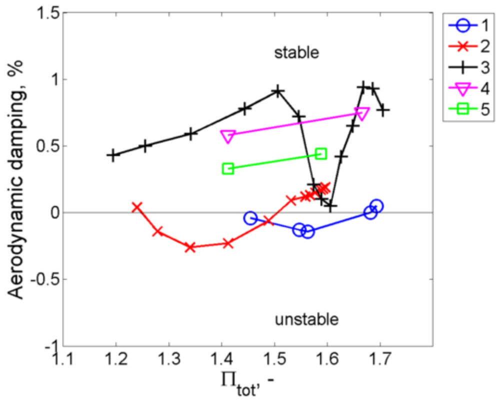


Figure 6. Comparison of predicted aerodynamic damping (5 different project partners).

It is thereby noticeable that two out of five partners predict flutter, whereas the other three predict a stable situation. On the background that all these partners are known experts in aircraft engine components, these results underline the uncertainty presently associated with flutter predictions.

One of the major benefits from the FUTURE project will be generated from a comprehensive assessment of the various numerical tools. Validation and calibration will be performed on the unique set of test data acquired in the project. Best practice guidelines will be elaborated that shall help making flutter predictions more accurate and reliable while not compromising on computational costs.

5. Conclusions

Flutter is and remains one of the key limiting phenomena when designing the next generation of "green" aircraft engines. Due to its harmful nature, flutter needs to be avoided at any costs. As engine design processes increasingly rely upon numerical prediction tools, these tools need to be validated on relevant test cases to ensure prediction accuracy and reliability. The EU FP7 funded project FUTURE employs a number of new and unique compressor and turbine flutter test cases that are representative for modern aircraft engines. The goal of the project is to acquire a new set of flutter validation data, against which a variety of state-of-the-art numerical prediction tools will be validated. Meeting the goals of the FUTURE project will give the project consortium the advantage of being able to predict flutter at a higher degree of accuracy. In a wider perspective, this will provide key enabling technology for designing "green", safe, reliable and affordable aircraft engines, now and in the future.

References

[1] www.newac.eu/17.0.html, accessed on 2011-06-09.
[2] T.H. Fransson, 1999, "Aeroelasticity in Turbomachines", VKI Lecture Series, May 1999, Rhode-Saint-Genèse, Belgium.
[3] A.R. Collar, 1946, "The Expanding Domain of Aeroelasticity", The Royal Aeronautical Society, London, UK, 1946, pp. 613–636.

[4] A. Meldahl, 1946, “Selbsterregte Flügelschwingungen mit einem Freiheitsgrad”, Brown Boveri Mitteilungen, Nr. 12, 1946, pp. 386–393.
[5] J. Panovsky and R.E. Kielb, 2000, “A Design Method to Prevent Low Pressure Turbine Blade Flutter”, J. of Engineering for Gas Turbine and Power, Vol. 122, January 2000, pp. 89–98.
[6] Y. El-Aini, R. de Laneuville, V. Soner and V. Capece, 1997, “High-Cycle Fatigue of Turbomachinery Components – Industry Perspectives”, AIAA Paper 97-3365.
[7] H. Mårtensson, J. Östlund, R. Bladh and B. Grüber, 2011, “Design and Analysis of a Transonic Flutter Research Compressor”, IFASD paper IFASD-2011-171.

About the Author

Damian Vogt and Torsten Fransson work at the Division of Heat and Power Technology at the Royal Institute of Technology in Stockholm, Sweden, where they lead the EU FP7 funded project FUTURE.
damian.vogt@energy.kth.se
torsten.fransson@energy.kth.se
www.energy.kth.se

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-168

Validation of Radical Engine Architecture Systems: The "DREAM" Research Project

David BONE

Abstract. "DREAM" – validation of Radical Engine Architecture systems – is a Framework Programme 7 Call 2 project with a total budget of €40 million and which is in its fourth and final year in 2011. This project comprised of 44 partners from 13 countries from the EU, Switzerland, Russia and Turkey and comprised of larger Original Equipment Manufacturers (OEMs), SMEs, universities and research establishments. It is the response to commercial and environmental pressures that have come about mainly as a result of two main factors: the continued pressure to reduce CO_2 and the future availability and cost of Jet A1 fuel. "DREAM" has studied designs for contra-rotating open rotors and has been developing novel systems to achieve, versus Year 2000 reference engines: (i) a reduction in CO_2 by 27% (7% better than ACARE goals); (ii) a reduction in noise by 9 dB cumulative.

Keywords. Engine architecture, blades, turbines, contra-rotating open rotors, geared open rotor, low pressure turbine, direct drive open rotor

1. Some Historical Background

During the early to mid 1980s there was significant pressure on the airlines to contain the impact of the escalating cost of Jet A1 fuel caused by the escalating price of crude oil. This resulted in increased efforts by both the airframe companies and the engine companies to achieve significant reductions in aircraft fuel consumption.

It was known that conventional propeller engines offered substantial fuel burn advantages over their turbofan engine equivalents. However there was a significant downside in that turboprop engines of the time only achieve Mach numbers of up to 0.6M which, if selected instead of turbofan powered aircraft, would have major impact on flight schedules and passenger expectations.

The drive was to use modern methods to design an efficient open rotor propeller to maintain its efficiency at the much higher cruise Mach numbers typical of the latest short-range aircraft (M = 0.78 to 0.8). To achieve this, the engine and airframe companies looked to the development of advanced open rotor propellers. Features that the engine manufacturers researched were:

- Swept blades for higher speeds;
- Greater number of blades;
- Blades with lower thickness/chord ratios;
- Higher hub/tip ratios;
- A second row of counter-rotating blades to eliminate net swirl.

Figure 1. The GE36 Engine.

Figure 2. The P&W/Alison 578-DX Engine (source flightglobal.com).

There were two demonstrator engines developed in the West:

1. General Electric successfully ground-tested and flew an open-rotor GE-36 engine (also known as the UDF™) This engine had direct drive contra rotating propellers that were driven directly from contra-rotating statorless turbines (Fig. 1).
2. The Pratt & Whitney/Alison 578-DX engine (also known as the Propfan™) which had a reduction gearbox between the LP turbine and the contra-rotating propellers which consisted of two rows of 2.95 m (11.6 ft) diameter blades: six in the front row and six in the aft row (Fig. 2).

Figure 3. The Progress D-27 Engine (source damtp.cam.ac.uk).

In addition the Progress D-27 engine was developed in the U.S.S.R for the Antonov An-70 military transport where four engines were fitted in a tractor configuration. It was also planned that this engine would power the Antonov An-180 passenger airliner with two engines in a rear-mounted configuration. This aircraft was scheduled for a 1995 entry into service but was subsequently cancelled. Another Russian propfan application was the Yakovlev Yak-46.

The UDF™ and the Propfan™ were both able to deliver high Mach speeds (0.72 to 0.8) and significantly reduced SFC, although the noise levels from the were well in excess of those achieved by existing turbofan engines.

The drop in oil prices in the late 1980s, coupled with little global interest to reduce CO_2, resulted in less interest from the airlines, and consequently there was no further development of the Open Rotor concept.

In 2000, an increased focus on climate change resulted in the creation of the ACARE 2020 goals:

- Reduce fuel consumption and CO_2 emissions by 50% (20% for the engine alone);
- Reduce perceived external noise by 50%;
- Reduce NO_X by 80%.

In addition, fuel prices continue to oscillate, but the trend is likely to be upwards over the coming years (Fig. 4).

The DREAM project is the response of the engine community to address these environmental and commercial pressures.

DREAM is studying a range of novel designs for both contra-rotating open rotors and turbofans by:

- Exploiting progress made since 1990 in 3D fluid dynamics methods in steady and unsteady conditions to increase the aerodynamic efficiency while reducing noise levels;

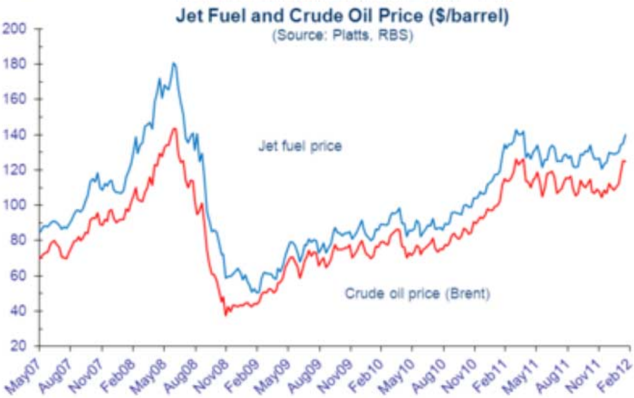


Figure 4. Increasing Trend in Fuel Prices (source Platts RBS).

- Performing tests on contra-rotating rigs to measure aerodynamics and noise that will feed the simulation models;
- Developing novel engine systems including active and passive vibration control, engine structures with additional functionally and active solutions for turbines such as smart active clearance control and active boundary layer control;
- Validating the use of alternative fuels in these aero engines and demonstrating green house gas emission reduction.

DREAM was awarded is a Framework 7 Call 1 Level 2 project started in February 2008, initially as a three year project but it was subsequently extended to four years. The project consists of 44 partners from 13 countries with expertise and capability from within the EU, Switzerland, Russia and Turkey and a wide variety of organisations including larger OEMs, SMEs, Universities and Research establishments.

The project objectives reflect the major step forward in engine technologies and are aimed at achieving or bettering the ACARE 2020 goals at rig demonstration technology level.

The objectives are for the engine and pylon in isolation:

- CO_2 – 7% better than ACARE or 27% better than Year 2000 engine;
- Noise – 3 dB per operation point (~ –9dB cumulated on 3 cert points) versus the Year 2000 engine.

One of the major aspects of the project is to study the aero and noise performance of contra-rotating open rotors. This architecture offers a step change in propulsive efficiency compared to the turbofan engine, but it will be noisier than an equivalent advanced turbofan engine (Fig. 5).

The factors influencing the optimum design of the open rotor system results in a compromise between the installation of the engines and resultant noise (Fig. 6).

2. Project Structure

The project consists of 5 technical Sub-Projects supported by a Coordination Sub-Project that handles the management activities within the project. The Sub-Projects

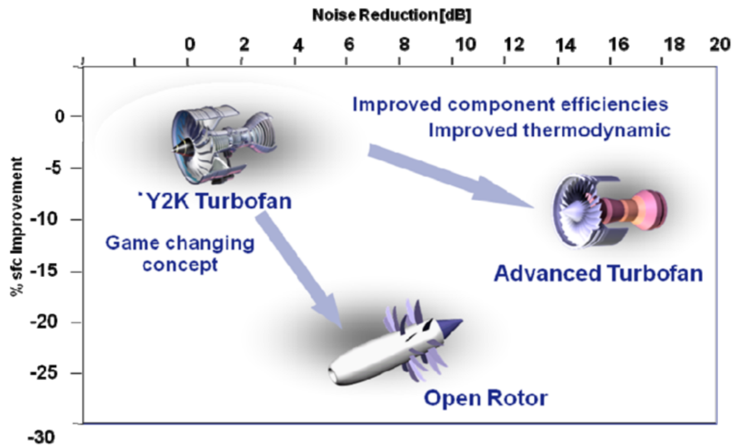


Figure 5. Open Rotor/Advanced Turbofan Efficiency and Noise Comparison.

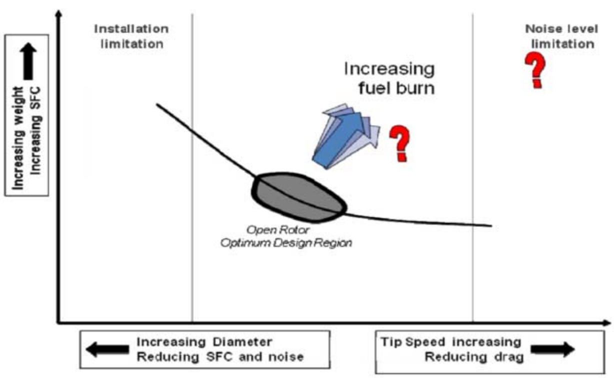


Figure 6. Optimum Design of Open Rotor System.

have been constructed to enable the partners to focus on key technical elements of the project and also to ensure project integration.

The structure of the project is shown here below (Fig. 7).

2.1. Technical Sub-Projects

2.1.1. Sub-Project 1 – Whole Engine Architecture

The objectives of SP1 are to:

- Define the aircraft specifications that set the DREAM engine requirements both for open rotors architectures and advanced conventional turbofan technologies;
- Compare, assess and rank the systems investigated within DREAM by their technological potential whilst achieving environmental goals;

Figure 7. Project Structure.

- Provide requirements and objectives of each different DREAM engine technology;
- Establish how the propulsion system compare to the ACARE goals and assess the possible shortfalls;
- Use of a Techno-economic Environmental Risk Analysis Model known as TERA 2020.

The work completed on SP1 is:

- Through an active cooperation involving all SPs partners, a detailed assessment process defines a clear, fair and complete comparison of all engine architectures benefits vs Year 2000 engine configurations. This assessment process covers fuel burn (metrics for pollution and economics), and noise on the certification points;
- Analysis has confirmed promising figures for fuel burn target;
- On the Techno-economic Environmental Risk Analysis Model concept models of open rotor modules have been created and verified against available data and OEM experience and these have been integrated into a fully operational optimization environment, enabling sensitivity and trade off analysis regarding fuel burn, emissions and noise.

2.2. Sub-Project 2 – Geared Open Rotor

The objective of SP2 was to carry out research surrounding the development a geared Open Rotor engine. It is broken into six work packages:

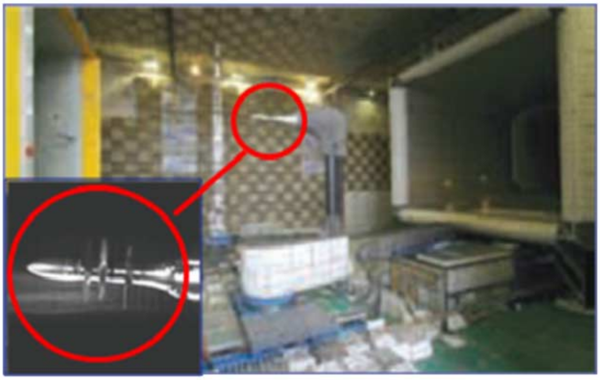


Figure 8. Low Speed Rig Testing at DNW.

Figure 9. Pitch Control Bearing Rig.

- *Architecture and Specification*

  Test data from the Rolls-Royce Open Rotor rig (Rig 145) on an initial set of propeller blades running at DNW in Holland and ARA the UK has permitted for an optimised re-specification of an optimised design and test programme

- *Installed and Uninstalled Aero/Acoustic Rig Testing (2 Work Packages)*

  The SP2 *objectives* to generate and capture aerodynamic and noise data from rig testing on the initial design of blades and the optimised design of blades have been achieved.

  The optimisation of data allowed (Fig. 8):

  - Further enhancements in the understanding of low and high speed optimisation at different RPM/Pitch/Mn configurations to increase Open Rotor understanding;
  - Improvements in the understanding of test data correction and correlation;
  - Acquisition of data to understand change in performance relative to design points chosen;
  - Build knowledge database at different conditions to increase confidence in CFD and its understanding;
  - Acquisition of quality data to understand key aero-mechanical parameters.

- *Pitch Control and System Integration*

  Rolls-Royce and SCITEK have developed a test rig to undertake bearing friction measurements under conditions representative of open rotor technology (Fig. 9).

  Novel hydrostatic bearings have been designed and manufactured to apply centrifugal and thrust loads in a frictionless manner. Real-time control and data acquisition is employed to obtain high speed, high accuracy bearing friction measurements. Test data from the rig will feed directly into the design and control system of the Pitch Control Mechanism (PCM) of an open rotor engine.

Figure 10. Geared Open Rotor LP Turbine.

- *Low Pressure Turbine Design*

This WP aimed to develop the design of an optimised Low Pressure Turbine for the geared open rotor configuration by:

- Defining and validating aerodynamic technologies to maximise efficiency;
- Defining low weight technologies for use in geared open rotor engines;
- Developing the design and analysis methods required in the design to predict life.

Technical progress throughout the project has enabled the characterisation and design of a High Speed Low Pressure system (Fig. 10).

Aerodynamic testing has been carried out the data analysis. Experimental results have been fed back to conceptual design to select the optimum solution taking account efficiency, weight and noise.

Detailed design has been developed for critical parts and to demonstrate potential opportunities, when necessary.

In DREAM, ITP, with the collaboration of partner Universidad Politecnica de Madrid, has worked to develop an understanding of High Cycle Fatigue in Low and High speed turbine designs.

- *Hot Structures*

The main objective of this Work-Package is to explore the implications of the new engine configuration onto the hot structure design and to achieve an optimised design concept for the cycle provided. Technical progress throughout the project has enabled the detailed design of a Hot Structure with a significant reduction in weight and cost.

The first step was focused on selecting the appropriate configuration (including material selection) for the aero turbine, paying special attention to deflections of the structure, vital to ensure the functionality of the whole engine.

The second step included the weight/cost optimization, taking advantages of new high-tech assembly/manufacturing techniques, which led to the detailed design of a light high resistant Hot Structure (Fig. 11).

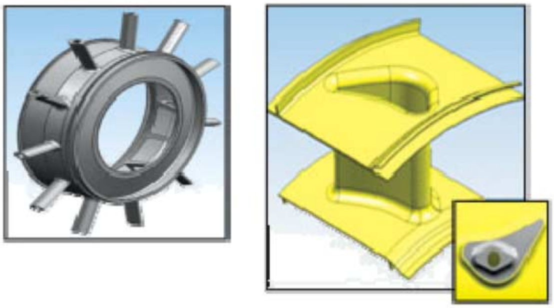


Figure 11. Hot Structures.

2.3. Sub-Project 3 – Direct Drive Open Rotor

The objective of SP3 was to develop an Open Rotor based upon a Direct Drive concept. This has been undertaken in 5 Work-Packages:

- *Specification and Management*

  The main activities of this Work Package were to coordinate activities between the SP3 partners and the DREAM Management Committee, to derive specifications for the modules studied inside this sub-project and to provide the final Direct Drive Open Rotor assessment to Sub-Project 1.

- *Perform Open Rotor Propeller Blades Detailed Design and Evaluation*

  - Provided the definition of mock blades for aero and acoustic tests;
  - Studied the installation effects and design a mock pylon for installed tests;
  - Studied aero-acoustic advanced concepts for open rotor;
  - Performed aero-acoustic and mechanical assessment;
  - Evaluated the impact of smart blade concepts on blade design and performances.

- *Develop a Design for a Contra-Rotating Turbine*

  This Work-Package looked at three elements for the design of the contra-rotating turbine, and to investigate the new components which are introduced in the contra-rotating shaft line:

  - The contra-rotating drum containment capability was considered with dedicated test campaign. A new material for the Drum, based on wound fibres was assessed (Fig. 12);
  - Contra-Rotating Strut, which transfers the load from the Drum to the Contra-rotating Shaft was assessed in terms of strength and performance;
  - Contra-Rotating Blades: The effect of compression tensile status of vibratory capabilities of the blades was studied on a test on a rotating drum with simplified blades;

- *LP Compressor*

  This Work-Package looked at the design of an LP compressor to support the direct drive Open Rotor engine (Fig. 13).

Figure 12. Pre-stressed plates impact test.

Figure 13. 5 Stage High speed Open Rotor Booster (CIAM) and R4 bench (Von Karman Institute).

This work consisted of:

- The design of the Open rotor LP compressor;
- The design and test different technologies to improve the efficiency and the stability of the Open rotor LP compressor;
- An assessment the Open rotor LP compressor at engine level.

- *Evaluate the Aero and Acoustic Performances of the Contra Open Rotor Blades and Pylon*

  This work was carried out using wind tunnel installations at TsAGI (Russia) (Fig. 14). Six different geometries were tested in low speed and two geometries were tested in high speed conditions. Reverse thrust tests were also carried out on two geometries and the pylon installation effects were considered at both low and high speed.

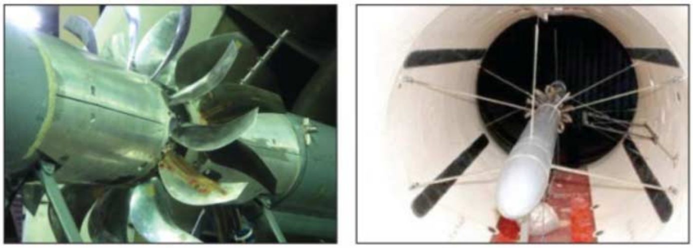


Figure 14. Low and High Speed rigs at TsAGI.

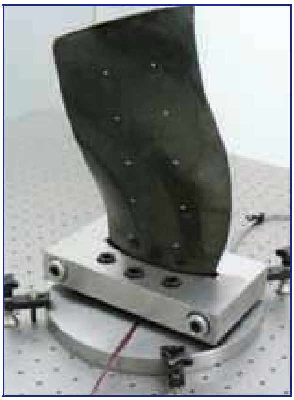


Figure 15. Active Damping of Fan Blades.

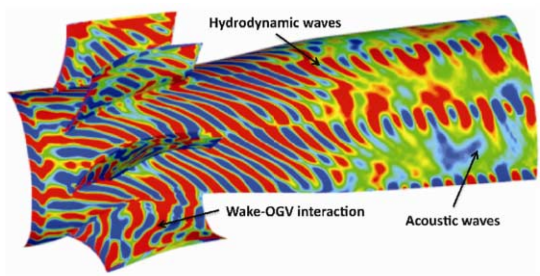


Figure 16. Ultra Low Count Fan Outlet Guide Vanes.

2.4. Sub-Project 4 – Innovative Systems

This Sub-Project consists of four work packages that provide enabling technologies for low weight and low cost future engines and also an efficiency improvement of 0.5% by adding innovative functionality and active solutions for turbines:

- *Specification and Assessment*

  This provides specifications for the technology assessed in this sub-project and provides the final assessment of the technologies to Sub-Project 1.

- *Development of Intelligent Vibration Damping Systems and Low Noise Structural Fan OGV*

  Active vibration control engine structure with piezo actuator damping systems and elastomeric damping rings for passive vibration control and cost efficiency (Fig. 15). This Work-Package also considers the design of a low noise ultra low count Structural Fan OGV (Fig. 16).

- *Novel Structure for Mid Frame*

  Two TMTF designs have been aero- dynamically designed and tested and High Velocity Oxy Fuel coatings tested (Fig. 17).

Figure 17. Evaluation of high velocity oxygen fuel thermal spray coating.

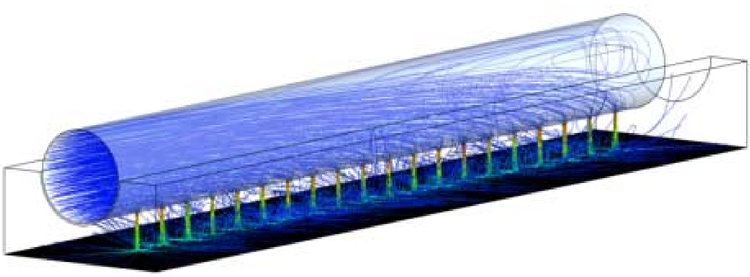


Figure 18. CFD simulation of a short section of an ACC tube with 20 impingement cooling holes.

- *Active Turbine*

  This Work-Package assessed and optimised the aerodynamic performance of active boundary layer control for high-speed conditions and to validate a closed-loop LPT active clearance control (ACC) system:

  - Different actuator configurations for pulsed ejection were tested in a turbine cascade in a high-speed wind tunnel;
  - ACC impingement cooling heat transfer characteristics examined by CFD simulations and experiments with scaled models and real ACC panels (Fig. 18);
  - A microwave sensor for radial clearance measurements was adapted for measurements with shrouded blades in a low pressure turbine, manufactured and tested in a test engine.
  - A closed-loop ACC system was investigated with a software demonstrator (Fig. 19).

2.5. Sub-Project 5 – Alternative Fuels Demonstration

This Sub-Project will demonstrate the performance of an existing available fuel (a Shell GTL type and a 3rd generation UOP SPK (HVO) fuel from Camelina):

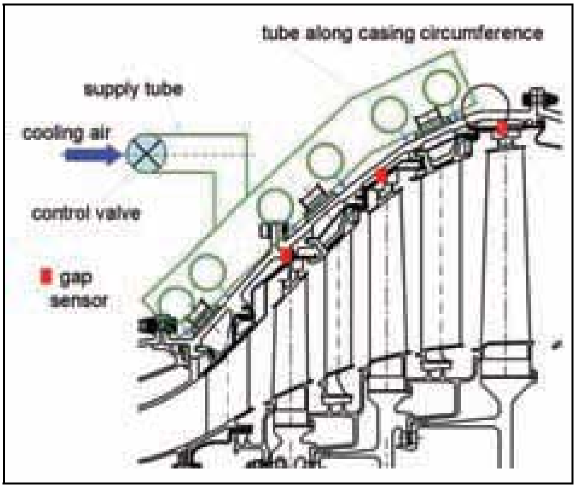


Figure 19. Closed Loop ACC System.

The requirements for the fuel are:

- No significant modification of aircraft or engine is needed (‘drop-in’ fuels);
- Contribute to the reduction of green house gas emissions (CO_2 emissions will be measured and compared with standard aviation fuel).

This consists of three Work-Packages:

- *Aircraft and Engine Impact*

  Two alternative drop-in fuels have been selected: a 50% GTL – 50% JetA1 blend provided by Shell and a 50% HVO – 50% JetA1 blend made of camelina oil provided by UOP. The impact of using these fuels was evaluated both on aero-engine fuel systems and on aircraft fuels systems. Tests needed to validate the use of the 2 selected alternative fuels.

- *Component Tests*

  This Work-Package looked at the effect of the alternative fuels on various engine components including fuel system, combustion system and elastomerics:

  - Fuel systems tests at Turbomeca (Fig. 20);
  - Combustion tests at Pars Makina (Fig. 21).
  - Altitude ignition tests at ONERA to check ignition performances of alternative fuels under altitude conditions (cold air, cold fuel, sub-atmospheric pressure) compared with jet-A1 (Fig. 22).

  Results of component tests

  Fuel systems performances with synthetic fuels are similar to performances with Jet-A1.

Figure 20. Rubber Immersion tests at Turbomeca.

Figure 21. Combustion Tests on Alison/RR C2500 Combustor at Pars Makina.

Figure 22. Ignition Tests at ONERA MERCATO.

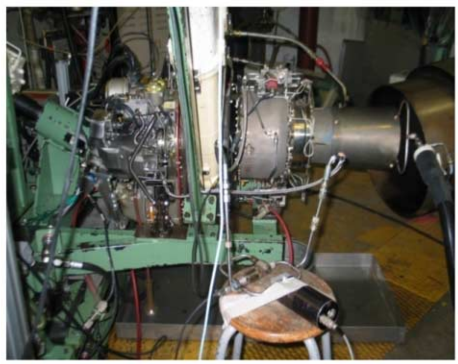


Figure 23. TM Arrius 2B2 engine installed for endurance tests.

No major disparities have been found between alternative fuels and reference Jet A1 during the combustion test conducted with small helicopter turboshaft engine.

During the ONERA MERCATO test campaign unexpected clogging was encountered at –15°C with HVO blend. A second test campaign confirmed this behaviour. Complementary investigations have been performed by UOP on the HVO blend from the same batch than the one used at ONERA MERCATO. It was demonstrated that the origin of the clogging was due to a contamination of the fuel batch, and was not linked to the HVO type bio-fuels.

- *Engine Demonstration*

The objective of this Work-Package was to demonstrate that alternative fuels can be used in an aeroengine without major modification. The engine demonstration was performed at Turbomeca on an ARRIUS 2B2 prototype engine with the HVO blend (Fig. 23).

The engine demonstration included:

- Performance tests with Jet A1 and the HVO blend;
- Lean blowout tests and emissions measurements with Jet A1 and the HVO blend;
- 60 hours of endurance tests with the HVO blend.

The tests were followed by a strip down and examination of the engine and a check of fuel systems equipment.

- *Results of Sub-Project 5*
  - The overall behaviour of the engine with HVO blend is consistent to engine behaviour with JetA1.
  - The endurance with HVO blend was successful.
  - HVO effects on Emission Index (EINOx, EICO, EIHC) compared to Jet A1 are lower than engine to engine variability.
  - HVO effects on Smoke Number levels compared to Jet A1 are lower than the uncertainty of the measurement process.
  - The tests validated the fuel system functional requirements ‘compatibility with materials’ and ‘lubrication of the fuel system components’.

3. DREAM Overall Summary

DREAM is now coming towards its completion. The project has been instrumental in taking forward the knowledge on Open Rotor technology; in particular the results from the project indicate that it is possible to engineer an Open Rotor engine solution that provides a step forward in engine efficiency and also capable of achieving acceptable engine noise levels. There is a considerable amount of work that would still need to be carried out to integrate such an engine on an airframe and to show conclusively that the full installation effects can be managed. However DREAM, which looks at the engine and pylon in isolation, will achieve its objectives with respect to both efficiency and noise.

The project has also carried out important research into novel systems. The technology developed and the knowledge gained during the course of this work has shown that there are potentially valuable gains to be had if these are incorporated in future engines, in particular enabling the implementation of the Open Rotor concept.

Lastly, the work carried out on the alternative fuels demonstration has provided valuable information on the characteristics and operation of GTL and HVO fuel both at component level and at engine demonstration level. This has greatly increased the understanding on the use of alternative fuels and, along with work carried out elsewhere on this topic, will support decisions to be made on the future use of these fuels.

About the Author

David Bone is the European Programme Manager for Rolls-Royce plc[1] and has been the Coordinator of the "DREAM" project since its award.

Rolls-Royce plc – PO Box 31 –
Derby DE24 8BJ – UK –
Tel.: +44 (0) 1332 249842
dave.bone@rolls-royce.com
www.rolls-royce.com

[1] Rolls-Royce employs around 38,000 people worldwide, including 23,500 in the UK, 5,000 in the rest of Europe and 8,000 in North America. A significant amount of Rolls-Royce technology investment is directed towards reducing noise and emissions.

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-184

Main Achievements of VITAL (enVIronmenTALly Friendly Aero Engine)

Marius GOUTINES

Abstract. VITAL programme started in January 2005 and was completed in December 2010. It was devoted to investigation of architectures and technologies able to reduce aero-engines environment impacts. The two main specific objectives of VITAL were a reduction of community noise by 6 EPNdB per operation and a reduction of CO2 emission by 6% (i.e. –6% fuel burn). This paper presents a brief description of the main achievements in each investigated turbofan domain.

Keywords. Environmentally friendly aero-engine

1. Introduction

VITAL scope was focused on low pressure (LP) modules for high and very high bypass ratio (BPR) turbofans. In accordance with VITAL objectives the research actions were to investigate and evaluate low noise, low weight and high aerodynamic efficiency technologies for LP modules.

This programme was led by Snecma and involved 53 partners. All main European engine manufacturers participated to VITAL as well as members of aero engine industry supply chain and small or medium enterprises (SME) with specific expertise. Key Russian and European research institutes brought to VITAL a very highly valuable contribution.

2. Single Fan (RR Led)

A fully instrumented direct drive fan has been tested in the "ANECOM" aero-acoustic rig. Following results were obtained:

- 2.5% fan efficiency improvement versus 2000 State-of the Art (SoA), with Technology Readiness Level 4;
- Fan noise reduction participates at the 15 EPNdB (cumulative) improvement, at engine level, versus 2000 SoA and with TRL 5 level.

30% of weight reduction has been obtained at fan system level with TRL 5 maturity. Fatigue, bird strike and blade release tests have been completed on hybrid composite RTM/metal blades.

Figure 1. Fan installed in ANECOM anechoic aero rig (RR).

Figure 2. Fan rotor ready for blade release test (RR).

Figure 3. Contra turbofan model (Snecma).

Figure 4. Front view of a contra fan model (Snecma).

Figure 5. Contra fan model in CIAM anechoic rig.

3. Counter Rotating Fan or CRTF (Snecma Led)

3 fully instrumented models of 3 new CRTF designs have been tested in "C3-A" aero-acoustic test rig by CIAM (Russia). This bench allows forward and aft noise measurements. Main achievements with TRL 4 were:

- Tests of different rotor spacing, blade shapes, loading radial distribution and blades number (10 × 14 and 9 × 11);
- +2.5 point efficiency benefit versus 2000 SoA reference single fan;

Figure 6. Composite full scale fan frame demo (Volvo Aero).

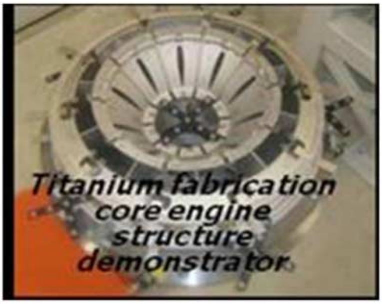


Figure 7. Titanium core engine structure demonstration (Volvo Aero).

Figure 8. Turbine structure, sub-scale super alloy demo (ITP).

- No noise benefit versus 2000 SoA single turbofan at same BPR was obtained. This is due to the two rotors interaction tones stronger than expected. Further research studies are still needed on this phenomena.

4. Structures (Volvo Aero Led)

Several structures concepts were brought at TRL 5 with weight reduction potential and production process verified in comprehensive manufacturing and mechanical tests. Following results have been obtained:

- A full scale polymer matrix composite fan frame saving 25% weight versus 2000 SoA;
- Titanium fabrication of a core engine structure saving 15% weight vs 2000 SoA;
- A super alloy hot structure for turbine, saving 18% weight versus 2000 SoA.

5. Low Pressure Compressor (Techspace Aero Led)

A low speed booster with increased stage aero-loading has been tested, fed by an upstream clipped fan, leading to TRL 6 validation. A high speed booster with increased

Figure 9. Low speed booster test in CIAM aerodynamic rig.

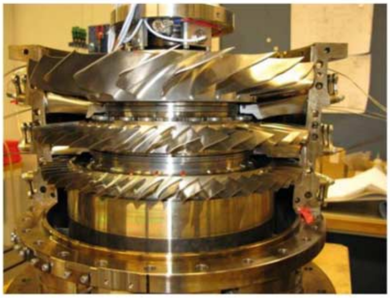


Figure 10. High speed booster rotor.

Figure 11. AVIO turbine aerodynamic rig.

Figure 12. MTU rig assembly ready for aerodynamic tests.

Figure 13. ITP turbine rig.

aero loading was also tested and TRL 4 achieved for this configuration. Aerodynamic researches are still needed to increase stability margins and efficiency for those highest aero-loadings.

6. Low Pressure Turbines (MTU Led)

3 approaches were adopted for weight and noise reductions:

Figure 14. Scale 1 MMC shaft machined at Volvo Aero Norway.

Figure 15. Multi-metallic shaft specimen.

- UHL: Ultra High Lift blading consisting in reducing the blade rows solidities (AVIO);
- UHSL: Ultra High Stage Loading, increased $\Delta H/n.U^2$ (MTU);
- UHAR/LN: Ultra High Aspect Ratio and Low Noise design (ITP).

The best obtained results are:

- 20% weight reduction, with only 0.5 point efficiency penalty, at TRL 5 maturity. This gain could be brought up to 30% with TRL 3 level;
- 3 EPNdB noise reduction in aircraft approach condition, at turbine level and with TRL 4. This gain could reach 4.5 EPNdB with TRL 3.

7. High Torque Density Shaft (Snecma Led)

A first investigated way was the MMC shaft (Titanium Matrix Composite with SiC fibers). An increase of torque density by 50% was obtained with TRL4 but research is still needed to improve the performance of the titanium/steel welding.

A second investigated way was a multi-metallic shaft. 50% of torque density increase was also obtained with TRL 4. For this technology research is also still needed to improve corrosion protection.

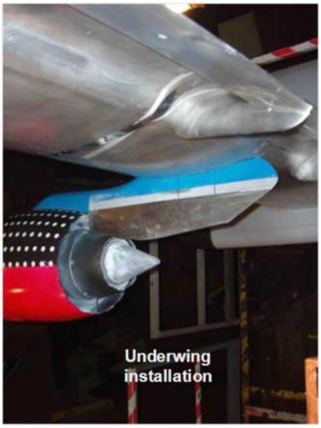


Figure 16. VHBR nozzle with chevrons installed in CEPRA19 anechoic low speed wind tunnel.

8. Installation and Thrust Reverser (Snecma Led)

A first topic of the investigation was the wing effect on Very High By-Pass Ratio engine jet noise. Acoustic interactions and masking effects have been quantified and can be use for actual predictions. A second topic was to establish guide lines for innovative lightweight nacelle and thrust reverser.

9. Conclusions

VITAL programme matured to TRL 4 or 5 advanced technologies for Low Pressure modules of advanced ducted engines (HBR and VHBR turbofans or counter rotating fans). Further research works are needed to reach TRL 6, required level to launch low risk development programmes. Main achievements are related to efficiency, weight and noise improvements.

About the Author

Marius Goutines – Snecma (Safran Group)
Research & Technology Programmes
Snecma Villaroche
Rond-Point René Ravaud, Réau
77550 MOISSY-CRAMAYEL, France
Tel: +33 (0) 1 60 59 71 39
Mobile: +33 (0) 6 08 23 39 42
e-mail: marius.goutines@snecma.fr
www.snecma.com

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-190

CRISIS: Multi-Trainee, Multi-Organisation, Multi-Level Critical Incident Management Training and Simulation System

B.L. William WONG

Abstract. CRISIS – Critical Incident Management Training System Using an Interactive Simulation Environment – is a European research project aimed at researching and developing a train-on-demand simulation platform for crisis management training. It started in May 2010 with a series of iterative user studies and participation in emergency exercises at Reykjavik airport (Iceland), Lisbon airport and Caiscais aerodrome (Portugal) and at the British Transport Police (UK). Training scenarios are being developed and used to specify the video game engine from which "crisis" will be designed to enable individuals, teams, and teams from various emergency services to train together in a multi-player environment.

Keywords. Critical incident, interactive simulation, training

1. General Objectives

CRISIS is a 36-month, 12-partner FP7 project aimed at researching and developing a train-on-demand simulation platform for crisis management training. It will train first responder supervisors and Emergency Operations Centre commanders, in real-time decision making and response to simulated critical incidents in virtual world replicas of airport and railway settings. CRISIS will support both collocated and distributed training across different emergency service organisations. CRISIS addresses the problem of infrequent crisis management training. Full-scale exercises are often conducted every two or three years, with two to three small scale exercises each year, as they are expensive to run and can significantly inconvenience the public.

The project started in May 2010, with a series of iterative user studies and participation in emergency exercises at Reykjavik Airport (Iceland), Lisbon Airport, Caiscais Aerodrome (Portugal), and at the British Transport Police (UK). Training scenarios are being developed and used to specify the interactive virtual world, to be developed in Unity3D, an advance commercial video game engine. Using this engine, CRISIS will be designed to enable individuals, teams, and teams from different emergency service organisations to train together in an immersive multi-player environment.

2. The Dual-Path Strategy

CRISIS will adopt a dual-path strategy in recognition of the different timeframes for research and development activities. In the development pathway, we will construct a more stable prototype that can be used as a demonstrator of the basic concepts es-

poused in the original proposal. We will use the research pathway as a means to experiment with new ideas that emerge from Work Package 6 Research and other work packages. For example, one of the concepts that evolved over the last year is the use of natural voice to communicate and coordinate actions among first responders and/or other control centre personnel. In the research pathway, we are experimenting with how such voice communications operate together with natural gesture interaction [5], techniques for eliciting requirements and consolidating them across different incident types [3]. To coordinate these two pathways we have organised in the first year, two 2-day research workshops to communicate research findings to the team, while several work package meetings have been held to share findings from field investigations and technical developments. This provides a common view of the simulation and training problem and language of expression.

3. Scope of the Crisis Simulation Environment

There will be two major components: The FielD eXercise or FDX component, and the Command Post eXercise or CPX, component. The FDX is a fine-grain, first-person shooter style interaction environment where the trainee will directly control the actions of the computer avatar to deal with the emergency in the simulation world. The CPX is a coarse-grain level simulation that corresponds with a command post or Emergency Operations Centre, where the emergency is represented on a computer-generated map display, together with other resource status displays and command and control information artefacts.

The trainee commanders will either speak directly with each other if located in the same venue or via the computer-supported communications (e.g. VOIP) if they are remotely located. Events that occur at the FDX level will be reflected in the CPX level systems, and directives given by CPX commanders will also be reflected in the FDX level. The red line in Fig. 1 indicates the boundary of operations and interactions that will be supported in CRISIS.

4. Modes of Training

CRISIS will provide three modes of training: Mode 1 is Individual-based training where the trainee will train against a full simulation where other team members are represented by the system. Mode 2 represent a training situation where real players are acting in a simulated environment and in the same location, while Mode 3 is when real players are connected through the computer simulation and are distributed or remotely located. This may be played at either the FDX or CPX levels, or collectively from FDX through to the CPX levels

5. Competency – Based Training

CRISIS will emphasise the training of competencies such as skills associated with problem diagnosis, planning, re-planning, and acting, rather than with procedure training or asking trainees to choose between pre-defined options. The emphasis in CRISIS

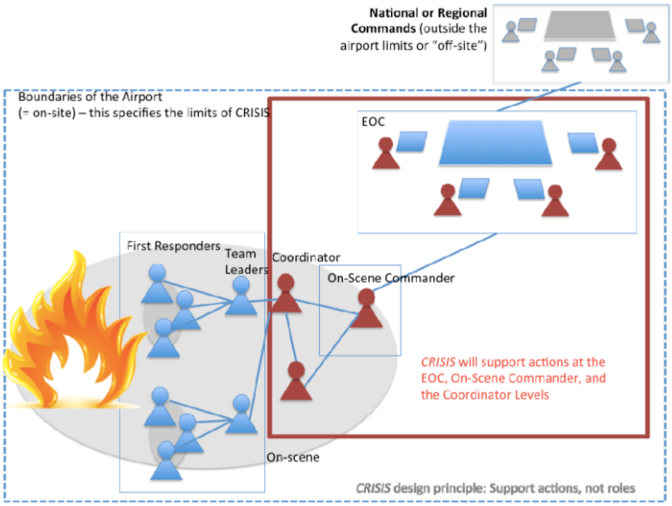


Figure 1. Bold red line indicates boundary of the CRISIS simulation system.

will be problem diagnosis and action generation; instead of the more familiar style of option selection.

Our study has identified 12 training gaps in these key competencies: assess alerts, assess risks, categorise crisis, communicate, communicate information, leadership, familiarise with procedures, formulate handling strategy, prioritise information, recognise strengths and weaknesses, resist pressure, and take control, and how this will help in developing resilience capabilities [4]. Our research found little demand for training hands-on type skills such as how to use a fire-hose or how to carry out medical treatment on a casualty. These would be better trained in other ways.

6. Support Actions Rather than Roles

Rather than to embed detailed sets of role descriptions and permissible actions of each role in a crisis management situation in avatars (e.g. fire commander, airport manager, and so forth), we decided to adopt a simpler design strategy that allows the avatar to activate actions in the simulation, rather than restricted to actions configured around the role an avatar plays. In the real world, roles can change quickly and dramatically, yet seamlessly. For example, the first fire fighter team leader to arrive on-scene will assume the role of the fire ground commander until a more senior commander arrives, at which point he reverts to his original role of fire fighting. To achieve such seamless transitions in the simulation will require much higher levels of detailed planning and software programming of the actions permissible, and to how those roles will be activated.

7. Whole-Task Training and Part-Task Training

CRISIS is being designed to support both part-task as well as whole-task training. Part-task training will enable individuals as well as small teams to carry out training in spe-

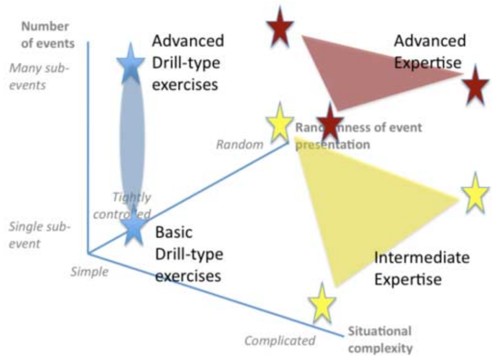


Figure 2. The Variable Uncertainty Framework.

cific aspects of crisis management. Such a scaffolding or ‘training wheels’ approach breaks down complex situations that enable novice trainees to develop their expertise before progressing. In addition, trainees will be trained to ‘prepare for the unexpected’ as complex situations demands flexible skills. CRISIS can achieve this by designing the simulation system such that exercise scenarios can be varied in ways that make repeated training using the same circumstances unpredictable, yet configurable by the instructor so that it still enables the trainer to target specific skill areas such as situation awareness or decision-making. We refer to this approach as the Variable Uncertainty Framework, discussed next.

8. Variable Uncertainty and Scenario Building

CRISIS will use the Variable uncertainty Framework or VUF [2], for re-creating the variability of real-world situations in the simulation. The VUF can be decomposed into three dimensions, which can be controlled: situational complexity of each event, the total number of events, and predictability of event presentation. Varying these dimensions will vary the difficulty of situations presented to trainees, from simple drills to the challenging (Fig. 2).

For example, simple well understood, single-sub-events that are tightly controlled, are good at providing trainees with practice in basic drills. Such drills-type of exercise can be made more challenging by introducing many sub-events thereby increasing workload or the rate at which the trainee must deal with them. By having a single sub-event, but increasing the situational complexity and the randomness by which events are presented, we can create training situations that demand a higher level of skills to respond to the presented situation. Then finally, by increasing the number of events that are presented, simultaneously or overlapping them, with high situational complexity and randomness, we can create situations that require an advance level of expertise.

9. Secure and Inter-Operable

The Secure Integration Platform will provide a component-based software architecture that would enable rapid integration of existing and new software components, and the

potential for connecting with real-world command and control systems. This work will start later in the project.

10. After-Action Review, Exercise Planning and Advanced Knowledge Management

CRISIS will have an Exercise Planning and After Action Review, AAR capability, enabling real-time injects, and rapid trainee performance evaluation. We are developing software to translate the Variable Uncertainty Framework into the exercise scenario planner. This will give the trainer the software tools and methods for controlling how events occur and how complex or demanding the events will be by setting the variability of start times or dependence on previous events.

The AAR system is expected to collect a vast amount of user performance data, and will require advanced decision and knowledge management technologies and visualisation techniques to facilitate rapid analysis. A proof-of-concept prototype has been developed using Drools to test the novel approach of integrating Topic Maps using rule-based reasoning and pattern detection to support to instructors during simulation training. Researchers are further investigating Esper as a basis for complex events processing for real-time analysis of events generated by the CRISIS system during training. An adapted a natural language question-answering interface to the scenario event data, is also being investigated to improve the question answering performance. In the absence of real data from the After Action Review module, researchers have developed a scenario data generator, using the Domain-Specific Language (DSL) paradigm. This will be used for defining requirements for real-time critique.

11. Realistic Scenarios

Photo-realism in simulation is not a major consideration for believability. Rather it is how well the emergency situations are constructed to make it believable. Our field investigations suggest that crisis managers from time to time experience shock and surprise when faced with sudden emergencies. We call these ‘startle points’ [1]. Startle can lead to a momentary inability to carry out their tasks, or a total failure to do so. We are using techniques such as the Critical Decision Method to identify cues and features that cause startle so that we can re-create the conditions in CRISIS in a believable way so that trainees can recognise when they are experiencing startle effects and to develop coping strategies. Teams from different organisations who are often unpractised at working together are often sent to emergencies. CRISIS is investigating how such teams cope with the lack of familiarity, and will identify characteristics of such situations and will attempt to re-create them in the simulations. The authentic use of sounds and communications in simulation can also add to believability. Sounds that do not match the scene can generate a high level of disbelief. Speaking with another person in the simulation scene should be comparable with physical world expectations, e.g. the voice of a person should become faint as one gets further from another person. We will research such sounds and methods for configuring them in the simulation, so that they can be designed to enhance believability.

12. Dissemination

In addition to a high level of dissemination activities (e.g. 19 refereed publications), we have also subscribed to Mendeley (http://www.mendeley.com/) the on-line reference manager and research social networking site. It forms a key part of our dissemination infrastructure. It provides a simple interface for the entire consortium to easily upload publications, and to share between partners and with other researchers who are allowed access to the CRISIS account. In this way, it increases the dissemination reach of our work. This will complement the material already available through the project's website (http://idc.mdx.ac.uk/projects/crisis/).

13. Conclusion

In operation for just over a year, CRISIS has made significant progress in understanding the problem of critical incident management and how we can use simulation environments to supplement crisis managers' training. Ideas are also emerging about how we might exploit the research in the future. We envisage CRISIS being capable of being reconfigured and re-purposed by enabling users with limited programming ability to configure the simulation from the given set of avatars, props and their behaviours, thereby allowing the same system to be used to create environments to train crisis managers at other airports, rail crossings, or even a football stadium. In addition, it can also be used as a test-bed for the un-thinkable by creating new threat scenarios and evaluating our plans against them.

Acknowledgements

This project received funding from the European Commission's Seventh Framework Security programme FP7-SEC-2009-1, under Grant Contract No. FP7-242474 awarded to Middlesex University. We thank our partners in the project: Crisware (DK), the National Aerospace Laboratory NLR (NL), ObjectSecurity Ltd (UK), Space Applications Services N.V./S.A. (BE), VSL Systems AB (SE), Linköping University (SE), Haskoli Island (IS), AE Solutions Ltd (UK), ANA Aeroportos de Portugal (PT), British Transport Police (UK), and ISAVIA Ltd (IS), and for the continuing support of our Senior Project Officer Alexandros Bakalakos.

References

[1] J. Barnett et al., Startle points: Identifying situational cues, and their implications for developing realistic emergency training scenarios. In ISCRAM 2011, ISCRAM conference: Lisbon, Portugal.

[2] J. Field, A. Rankin, J.v.d. Pal, H. Eriksson and W. Wong, (2011). Variable Uncertainty: Scenario design for training adaptive and flexible skills. Paper presented at the European Conference on Cognitive Ergonomics ECCE 2011, 24–26 August 2011.

[3] E.T. Hvannberg and J. Rudinsky. Crisis management training: Techniques for eliciting and describing requirements and early designs across different incident types. In 6th International Conference on Universal Access in Human-Computer Interaction, HCII 2011. Orlando: Springer.

[4] A. Rankin et al., Scenario Design for Training Systems in Crisis Management: Training Resilience Capabilities. In Proceedings of Resilience Engineering Symposium. 2011.

[5] C. Rooney and P. Passmore, Gestural Interaction for Simulation Training, in Workshop for Embodied Interaction. The ACM Conference of Human Factors in Information Systems CHI 2011: Vancouver, Canada.

Table 1. Partners

	Partner		Key Role	Point of Contact
1.	Middlesex University	UK	Project Coordinator HCI, design, decision making	Prof. William Wong w.wong@mdx.ac.uk
2.	Crisware A/S	DK	Technical Manager Simulation development	Kristian B. Hansen kbh@crisware.com
3.	National Aerospace Laboratory NLR	NL	End-User Participation Manager, Training and simulation systems	Dr Jelke van der Pal Jelke.van.der.Pal@nlr.nl
4.	Object Security Ltd	UK	Software Security	Rudolf Schreiner ras@objectsecurity.com
5.	Space Applications Services NV	BE	Knowledge Management Systems	Mr Rani Pinchuk rani.pinchuk@spaceapplications.com
6.	VSL Systems AB	SE	After-Action Review and Exercise Planning	Dr Magnus Morin magnus.morin@vsl.se
7.	Linköping University	SE	Research Manager, Decision Technologies	Prof. Henrik Eriksson henrik.eriksson@liu.se
8.	Haskoli Island (University of Iceland)	HI	Dissemination Manager, User interaction	Prof. Ebba Hvannberg ebba@hi.is
9.	AE Solutions	UK	Critical Incident Training	Dr Rick Adderley rickadderley@a-esolutions.com
10.	ANA	PT	Airport Operations	Ms Isabel Rebelo isabel.rebelo@ana.pt
11.	British Transport Police	UK	Police operations	Det. Chief Sup. Mark Smith samantha.harris@btp.pnn.police.uk
12.	ISAVIA	IS	Airport operations	Hjalti Palsson hjalti.palsson@isavia.is

About the Author

B.L. William Wong is Professor of Human-Computer Interaction at the Interaction Design Centre of Middlesex University, London (UK). He is Project Coordinator for the European FP7 project "CRISIS"

Middlesex University – The Burroughs – NW44BT London – UK
w.wong@mdx.ac.uk
www.eis.mdx.ac.uk/research/idc/

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-197

Behavourial Science Modelling of Security in Airports: BEMOSA

Alan KIRSCHENBAUM

Abstract. The European R&TD project called BEMOSA – Behavioural Modelling for Security in Airports – aims at developing a dynamic and realistic model of social behaviour and security decision making to threats in airports. These objectives will be accompanied by advancing the state-of-the-art in behavioural modelling. By examining airports as complex organisations throughout Europe and focusing on key decision making groups such as control tower operators, security employees, service vendors and passengers, BEMOSA will deliver the basis for a comprehensive and practical training programme that considers all the airport security stakeholders. Presently a mock-up model is being evaluated and refined as a generic format for the training modules.

Keywords. Behavioural science, airport, terrorists, social organisations, security

1. Prime Targets

Airports have increasingly become industrial and commercial enterprises. This makes them prime targets for terrorists that aim to disrupt modern civil society. This threat is taken very seriously by all stakeholders involved, ranging from policy makers to airport management, and law enforcement agencies. In addition, such security threats are extremely costly in terms of money, complicating air/land side logistics and affecting

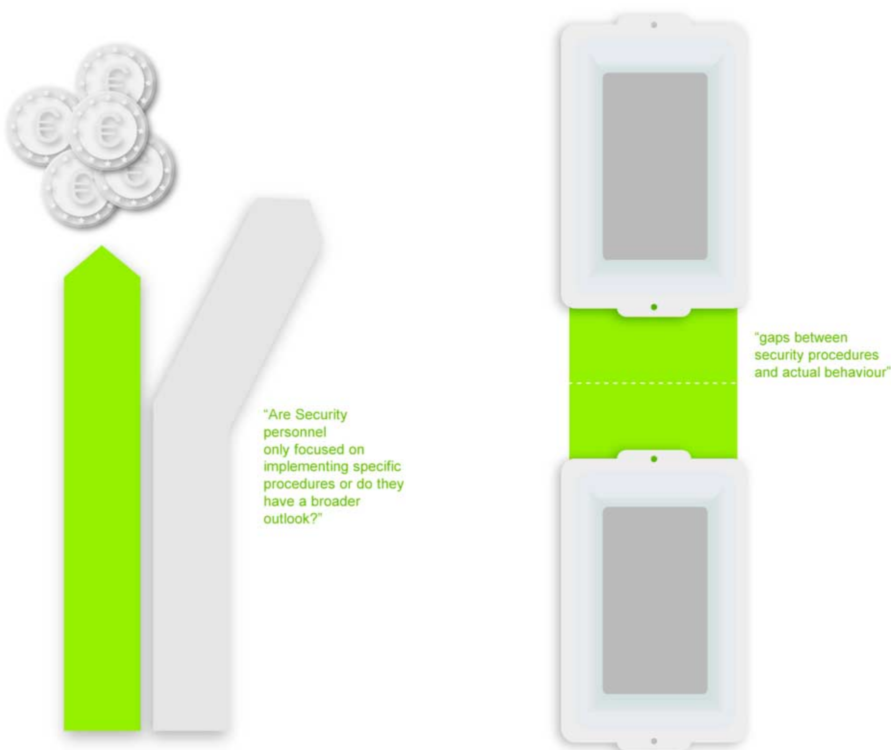
passenger satisfaction. These combined security and economic pressures make it imperative to leverage any investment in airport security as effectively as possible.

2. Who Makes Decisions?

Therefore, it is of no surprise that eliminating and mitigating threats to air traffic is one of the main objectives of the global air transport system. BEMOSA, an applied research project that is co-financed by the European Community, will contribute significantly to this objective by focusing on the human factors involved in the security decision making process. Emphasis will be put first and foremost on discovering actual security behaviours of airport employees and passengers. From this an analysis will be generated of the security decision making process within the social and organizational context of airports. Deciphering who, how and under what situations such decisions are made will form the platform for a scenario based simulation based training program. The end product will be evidence based training programs to enhance security decision making.

3. Airports Are Social Organizations

BEMOSA will provide answers and, more importantly, cutting edge applicable solutions for improvements in enhancing security decision making by strengthening human



resource capabilities. The basis for doing so lies in utilizing a holistic view of the airport as a large and complex organisation within which there exist both formalities between administrative units and a more subtle non-formal set of socially based communication networks that facilitate daily operations. As complex organizations, airports exhibit characteristics that influence employee behaviour through human resource management processes that relate to security issues. Therefore, it is important to understand how people behave in normal *routine* as well as *non-routine* situations.

4. Faulty Decisions Are Costly

Such an analysis should not only be limited to security personnel, but also to people working on the airport premises in general (across organizational boundaries) and even extended to the largest group of people in an airport: the passengers. What procedures are in place and are these procedures indeed drilled and implemented, especially during a crisis situation? Are security personnel only focused on implementing specific procedures or do they have a broader outlook? As is widely recorded, a crisis is an ever evolving situation when even most elaborate (static) plans cannot predict how decisions are made. And most important of all: what actual behaviour indeed contributes to increased security and what does not!

5. Procedures vs Reality

The research team of BEMOSA has already discovered specific gaps between security procedures and actual behaviour among a broad range of employees in airports of various sizes distributed throughout Europe. In addition, security decision making was found to be predominantly based on *group interaction* rather than individual decisions. This initial platform of evidence should provide a clear insight into how people behave and what behaviour contributes to enhancing security decisions. This base of evidence, along with a continuous flow of ethnographic, field survey data, interviews and longitudinal panel data should then generate a dynamic and realistic model of social behaviour and security decision making during security threats in airports. By examining airports throughout Europe and focusing on key decision making groups such as control tower operators, security employees, service vendors and passengers, BEMOSA will deliver the basis for a comprehensive and practical scenario based training program that considers all the airport security stakeholders.

6. How Decisions Are Made!

Unlike most available training packages, the BEMOSA training packages will be based upon how people make security decisions in the face of reality during the "normal routine" and crisis situations that occur in airports. The analysis of the ethnographic, interview and questionnaire data provides strong support for doing so within a scenario based framework. Given the empirical finding that such decisions are usually based on group interaction and in many cases discard or bend the rules, a scenario approach should compliment the present system of only learning the rules. This novel approach

will lead to increased efficiency of air transportation by decreasing false alarms, as well as improve safety and coordination for all stakeholders in cases of an emergency and security threat. It will provide breakthrough advancements in real-world crisis handling, reduce some well-known effects of stress and time pressure on human behaviour, and can be readily applied across cultural and organizational boundaries.

7. Cutting Edge Vision

Building scenario based training requires implementing advanced software simulations that will help to capture and predict social behaviour affecting security decisions under routine and non-routine situations, including emergencies which involve passengers. By thinking out-of-the-box, we hope to provide the platform for the training modules and training packages that can be readily applied at minimum cost to airports across Europe.

About the Author

Professor Alan (Avi) Kirschenbaum
Faculty of Industrial Engineering & Management – Technion – Israel Institute of Technology – Technion City
32000 Haifa, Israel
avik@tx.technion.ac.il.

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-201

SOFIA: Flight Automation as a Safe Countermeasure for Potentially Hostile Aircraft

Juan-Alberto HERRERÍA GARCÍA and Jorge BUENO GÓMEZ

Abstract. The SOFIA project (Safe Automatic Flight Back and Landing of Aircraft) is a response to the challenge of developing techniques enabling the safe and automatic return of an airplane to ground in the event of hostile actions. SOFIA validates the Flight Reconfiguration Function (FRF), which takes the control of the aircraft and manages to safely return it to ground under a security emergency (e.g. hijacking), disabling the control and command of the aircraft from the cockpit. This means to create and execute a new flight plan towards a secure airport and landing the aircraft at it. The flight plan can be generated on ground or in a military airplane and transmitted to the aircraft, or created autonomously at the own FRF system. For the validation of the FRF, SOFIA uses flight and Air Traffic Control simulators and General Aviation aircraft. SOFIA designs architectures for integrating the FRF system into several typologies of avionics; develops one of these architectures; and finally validates, following the European Operational Concept Validation Methodology (E-OCVM), the FRF concept and the means to integrate it in the current Air Traffic Management (ATM) system.

Keywords. Hostile aircraft, safe countermeasure, flight automation, flight reconfiguration function, security emergency

1. Introduction

Europe is already researching in this area, taking benefit from the 6th Framework Programme sponsored by the European Commission (EC) [1]. Within such initiative, several projects with participation of key European companies in the sector, are investigating the Flight Reconfiguration Function (FRF) arena such as SAFEE and SOFIA . These projects are the response to the EC concerns regarding aviation security. Such concerns are derived from the results achieved by the Advisory Council for Aeronautics Research in Europe (ACARE). They conform to the VISION 2020 paper and are presented in the ACARE Strategic Research Agenda (SRA2) [2]. The SOFIA outcomes rely on the SAFEE project results. Whilst the SAFEE project provides the aircraft with the capacity to detect the on-board hostile action and performs a diversion to take the aircraft up to a secure area, the SOFIA project controls the aircraft autonomously and lands it on a secure destination [3].

The FRF developed in the SOFIA project is the response from several leading European companies – Isdefe (coordinator), Deutsche Flugsicherung (DFS), GALILEO Avionica, Skysoft, Alenia SIA, THALES Avionics, Instytut Lotnictwa (IoA), Rheinmetall Defence Electronics (RDE) and Diamond Aircraft Industries – to the demand of the society to improve the security of aircraft operations. And the improvement is rea-

lized through an autonomous way, as requested by ACARE SRA2 [2]. Furthermore, SOFIA analyses the integration into the airspace of such an airplane flown by the FRF and its impact on the ATC system, and assess the implications of these developments in regulatory and certification frameworks.

2. Development Proposal

The main objective of SOFIA [3] is the validation of the Flight Reconfiguration Function system and the assessment of its integration into the airspace. SOFIA is mainly a technological project, but it also considers relevant operational and regulatory aspects. SOFIA dedicates an important effort in the assessment of those operational and regulatory issues related to the integration of the FRF system into the airspace. The operational assessment approach is not only a theoretical study but is also practical since the validation exercises consider the interaction of FRF with the airspace.

Taking the fact of the clear symbiosis between FRF and Unmanned Aerial Systems (UAS), SOFIA considers UAS developments and progresses as a constant reference for the project. This reference is not only present in the operational aspects, but also in the technological ones that enable the integration of the UAS into the airspace. For a few years, work is focused on the operation of UAS in non-segregated airspace, and in particular on the "sense and avoid" concept, that will enable to detect any other aircraft, and therefore to define and fly the appropriate trajectory permitting collision avoidance.

SOFIA follows a stepwise approach in its development which is formed by four main interrelated steps:

- Assessment on the issues related to the operation of the FRF;
- Design of the FRF system: functions, databases, components, interfaces, etc.
- Development of the FRF system for enabling the validation exercises;
- Validation of the FRF system and its integration into the airspace.

2.1. Step 1: Assessment of the Operational Issues

The main goal of this step is to define the future FRF environment by examination of (i) forthcoming avionics architectures and in particular those for FRF relevant features (Flight Control, Flight Management and air-ground communication) and (ii) the ATM environment which can be expected to be in place for the timeframe of FRF implementation (initially 2025). Thus, and together with the modalities of the FRF, the integration into that environment and the procedures required for the management of FRF-controlled aircraft can be defined. The task also assesses the avionics architectures where the FRF system will have to be integrated. This activity is quite interesting for the project because the determined environment for the FRF deployment is the reference for the whole project in two key aspects: FRF functions and validation exercises.

Once the FRF environment is defined, integrating the aircraft equipped with FRF into the airspace is the challenge. In the current situation, aircraft are controlled by pilots who interact with the air traffic controller (ATCO). The ATCO will command the pilot to execute maneuvers such as increase speed, change flight level, direct to a new waypoint etc. When due to on-board threats the FRF is put in control of the aircraft, data link remains the only possibility for the controller to communicate with the aircraft

by sending flight plans that the FRF will execute. But even this possibility can be disrupted. Then, the aircraft follows its own flight plan without any possibility of being controlled from the ground systems. In both events, new procedures are needed to guide the ATCO's behaviour. Such new procedures are proposed by SOFIA which also introduces the need of a Ground Security Decision Station (GSDS) to manage these security events.

Special focus is given on the regulatory and certification issues to which FRF integration gives rise. At this point, the reference to the UAS progress reveals crucial, and thus it is used as a main source to propose the appropriate regulatory and certification framework for FRF and the new procedures designed for its implementation. With respect to other projects dealing with the future ATM environment and tackling the problem of integrating autonomously flying aircraft, the distinctive feature of SOFIA is to take account of the security-related circumstances under which the autonomous flights occur. In this scenario, two questions will come up when the FRF and the new ATC procedures will be faced with the regulatory and certification frameworks: How will FRF and the procedures meet those frameworks? How could the frameworks be modified to enable the Flight Reconfiguration and the new ATC procedures by maintaining the safety levels?

2.2. Step 2: Design of the FRF System

Its main goal is to specify both the FRF system and its integration into the different avionics architectures that can be expected for the future, considering three modes of operation envisioned for the FRF:

- Flight Plan with Negotiation (FRF_N): the FRF executes a flight plan generated on ground and transmitted to the FRF via data link. FRF analyses the feasibility of the flight plan according to the aircraft conditions and performances. In case of agreement, the flight plan is executed. Otherwise, switch to next mode;
- Flight Plan without Negotiation (FRF_WN): after negotiation is finished without agreement or communication disruption, FRF executes the flight plan elaborated by itself, without any control from ground;
- Military aircraft relay: this is an intermediate step between the two previous solutions. FRF receives a flight plan from a military aircraft and operates as in the FRF_N solution.

As the FRF implied automation modes are expected to be at least partly present in future aircraft, SOFIA more specifically addresses the solutions allowing this automation and the associated mode transitions to be performed autonomously with no possibility for a malevolent onboard person to intervene. This will lead SOFIA to focus especially on FRF interfaces to existing systems and HMI devices, and to perform specific in depth safety analyses to define an architecture that fits all of the needs and constraints.

Figure 1 presents how FRF fits into the control chain in the aircraft replacing the pilot and directly interacting with the actuators of the airplane control and communication systems.

SOFIA studies in particular the autonomous flight re-planning function with the associated monitoring function, and the interfaces to available onboard surveillance systems which provide the means to detect various threats (equipment failure, terrain,

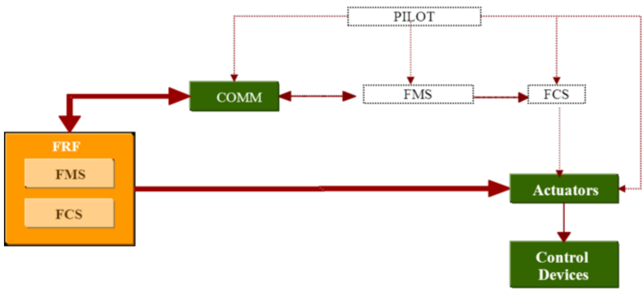


Figure 1. FRF Overall Architecture (Copyright Isdefe).

traffic, or weather hazard) and to autonomously make decisions about flight plan update. Especially for the detection of traffic threats, SOFIA will analyze and consider the most promising civil and military solutions under study in the UAS arena. It is a remarkable iterative process that will be run between the design activity and the regulatory, certification and safety assessments. As part of FRF design, SOFIA includes thus a study focused on data bases with the aim of identifying FRF-related requirements and specifying, with respect to the databases foreseen for future aircraft, the modifications and new data fields that are required to fit FRF needs and the set of databases that enables the calculations to be performed by FRF.

Also worthy of note is the innovation brought about by SOFIA at the ground side regarding the ATM procedures and tools, for which the impact of FRF related procedures and functions will be assessed. During the FRF design, a safety assessment is carried out. The main goal of this activity is to propose design requirements derived from the analysis of the preliminary design and the FRF integration into the airspace. Both safety assessments comprise the performance of a Functional Hazard Assessment (FHA) and a Preliminary System Safety Assessment (PSSA). EUROCONTROL EATMP SAM and SAE ARP 4761 are applied.

2.3. Step 3: Development of the FRF System

Its main goal is to develop the FRF functions for validation and to set up the simulation environment that allows FRF functional validation to be performed according to the objectives and requirements set out in the SOFIA validation plan. The task includes the adaptation of already available platform components and the development of appropriate new mock-up components in order to get functional test beds ready for carrying out of FRF validation. Only the operational modes FRF with Negotiation (FRF_N) and FRF without Negotiation (FRF_WN) will be carried out.

Six validation platforms are used in the SOFIA project:

- ATENA, flight simulator developed by GALILEO Avionica;
- AIRLABTM flight simulator developed by THALES Avionics;
- DFS ATC simulator;
- IoA’s I-23 Manager aircraft;
- Diamond Aircraft Industry Twin Star DA42 simulator;
- Diamond Aircraft Industry Twin Star DA42 aircraft.

2.4. Step 4: Validation of the FRF System and Its Integration into the Airspace

Its main goal is to perform the validation experiments envisaged for the SOFIA project to assess first, whether the design of the FRF system is capable of supporting the functionality required and second, the operation of FRF integrated into the ATC procedures as proposed by SOFIA. The validation exercises follow a validation plan elaborated according to E-OCVM.

The validation of FRF will only be made on the operational modes FRF with Negotiation (FRF_N) and FRF without Negotiation (FRF_WN). To carry out the validation, five experiments are proposed according to a stepwise strategy to feed back to the development phase validation results from a first set of validation exercises to refine the design and development of the FRF:

- A preliminary validation of FRF functions will be carried out during the development phase. The ATENA simulator is linked to the DFS ATC simulator. This experiment is focused on refining the FRF functions, particularly the assessment of the FRF functions and its integration into the airspace. The options Flight re-planning with negotiation and Flight re-planning without negotiation will be assessed;
- A flight trial is executed during the development phase to refine the development process by using an aircraft provided by IoA. This trial is focused on the assessment of Flight re-planning without negotiation;
- A validation exercise is run in the THA AIRLAB™ simulator to assess the feasibility of FRF solutions for the commercial aircraft world;
- Tests are performed in the Diamond Aircraft Industry Twin Star DA42 simulator to evaluate the integration of the FRF system into the DA-42 aircraft, previous to the validation of the FRF into the DA-42 aircraft;
- A flight trial by using an aircraft provided by DAI. This trial will be focused on the assessment of the Flight re-planning with negotiation thanks to a link to the DFS ATC facility;
- The validation cycle adopted in SOFIA is presented in (Fig. 2). This figure shows the links among the validation exercises, how they are used to refine the FRF versions developed in the project, and what validation platforms are used in each exercise.

The validation objectives are those related to the demonstration of the FRF concept reliability in realistic environments: Issues relative to the appropriateness and feasibility of the FRF operational modes, evaluation of the impact on the ground segment (ATCO work load, flight plan creation on ground), cross checking and execution of the flight plan and landing of the aircraft by FRF that are to be assessed in SOFIA. The next list addresses detailed validation objectives to be achieved in SOFIA.

- Validation of the impact of the FRF system on ground:
  - Assessment of the reliability of the new ATC procedures and management in a FRF scenario;
  - Assessment of the reaction of the ATCO when FRF is activated and workload ATCO upon the different FRF operational modes.

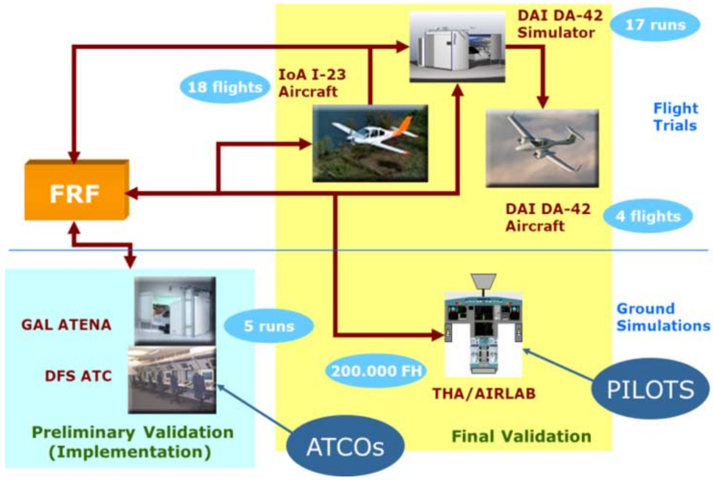


Figure 2. SOFIA Validation Cycle (Copyright Isdefe).

- Validation of the FRF system on-board:
  - Creation of the flight plan by FRF on air;
  - Crosschecking by FRF of the flight plan received from ground;
  - Execution of the flight plan and landing of the aircraft by FRF.

3. SOFIA Design Achievements

3.1. FRF Environment

In an emergency situation (e.g. a security crisis on-board as it is the case in SOFIA) the highest priority is to land the aircraft as quickly as possible. Therefore the flight to the selected aerodrome shall be as short as possible. The aircraft shall normally fly directly to the aerodrome. This part of the FRF flight will be the same for all the three FRF solutions introduced in the following paragraphs.

1. *Solution 1: Autonomous Flight Re-Planning*

For the FRF, it is very easy to create a new flight plan to a special emergency aerodrome, because all necessary information is available on board. The information about the crisis on board, the status of the aircraft and databases about the airspace are part of the safety and security systems. Information about the conditions at the selected aerodrome could be available, e.g. via ATIS. En-route weather information could also be received via data link or on board weather radar. As all information is available a route to the airport can be calculated quickly. FRF can down link the route to the GSDS, so ATC can keep the surrounding controlled traffic away. GSDS can also inform the selected airport and security authorities. In case of data link problems the FRF aircraft flies to the aerodrome without information to/from GSDS. ATC monitors the flight and, using predicting techniques (ATC tools), ATC can anticipate the possible aerodrome selected by the FRF system. Thus ATC can also inform that aerodrome and the authorities. This procedure is similar to today's procedure for an aircraft with r/t failure. Therefore this solution is easy to work, clearly structured and the time to pre-

pare is relatively short. This is the preferred solution for the controllers according to the outcomes from the workshop hold with them at the DFS.

2. *Solution 2: Flight Re-Planning with Negotiation*

Due to the negotiation between the FRF system and the GSDS, the preparation phase in Solution 2 is more time consuming. For the negotiation, data must be exchanged via data link. Depending on the technical equipment this data exchange may take longer. Additionally, during the negotiation phase two decisions must be taken. At first GSDS has to decide about the destination aerodrome (and the alternative); and secondly, the FRF system has to decide about the FPLN proposed by GSDS. Both decisions need extra time to compute. If the negotiation fails, the FRF uses the flight plan calculated by itself, reverting to Solution 1.

This information will be down linked to the GSDS through a secure data link. Regarding the premises made above, the aircraft will consume more time for the preparation phase than in Solution 1. Due to the decisions foreseen in the procedures, the structure of this solution is more complex. For the controllers this procedure is not as easy to work as Solution 1.

3. *Solution 3: Mil. A/C Relay*

Regarding the amount of time required and the complexity of the procedures, Solution 3 is the least preferred solution. Intercepting the FRF aircraft requires time. A specially equipped military aircraft must be informed and flown to intercept it. Then the military aircraft has to connect to the FRF aircraft and receive the status information. Based on this information the GSDS must calculate a new route to the emergency aerodrome. This information is to be transmitted via the military aircraft to the FRF flight. Then the FRF aircraft can start the flight plan. If the connection between the military aircraft and the FRF flight or the connection between the military aircraft and GSDS fails, the FRF system creates a flight plan and follows it to the emergency aerodrome. The interception of the FRF aircraft is time consuming and also the transmission of the data to GSDS via the military aircraft and back to the FRF aircraft is time consuming. Due to the integration of a third party (military aircraft) in the negotiation process the complexity of this solution is higher than in the other solutions.

4. *Discussion on the Solutions*

Initially a combination between the three solutions was envisaged. The proposed stepwise approach started with Solution 2, then Solution 3 and, as a last back up, Solution 1. This approach is very time consuming, very complex and not easy to work for all participating parties, particularly the Air Traffic Controllers (ATCOs). Therefore in SOFIA a clear structured solution is preferred. This preferred solution could either be Solution 1, Solution 2, or Solution 3. In Solution 2 and Solution 3 elements of Solution 1 are integrated as back up procedures if failures occur during the normal procedure. Thus a combination of Solution 2 and 1 or Solution 3 and 1 is foreseen, not as a stepwise approach but as one solution. However the preferred solution according to the ATCO's inputs is Solution 1.

3.2. Certification and Regulation

The SOFIA project has analyzed the impact of the Flight Reconfiguration Function (FRF) in the certification and regulatory frameworks. SOFIA has kept several meetings with ICAO, EASA and EUROCONTROL.

The major demand regarding certification activities was detected in the air segment. Although the philosophy underlying the design of the FRF system is to be pursued in compliance with the current regulatory framework, the existence of conflicts or gaps in current regulations is inevitable since the FRF is particularly innovative. Hence some changes in those regulations will be required in order to make the certification of the FRF system possible. Most conflicts detected in the current certification framework stem from the pilot being out of the loop when the aircraft is under command of the FRF system. In particular, the main associated issues are the fact that there is no pilot (1) to take over control of the aircraft when a critical system fails, and (2) to monitor malfunctions or emergencies on-board so that the pilot can react to them. Requirements have been derived and became a valuable input for the design of the FRF system from all the analysed codes for the air segment.

On the ATC segment the certification issues are not so problematic, as ATC does not influence directly the FRF flight, only the configuration of already existing certified ATC systems has to be changed. Also the interface to the GSDS is based on existing technology.

On the ground segment the GSDS is the only relevant system that has to be certified. Both the process and the responsibilities for such certification are not defined. As the GSDS has the ability to influence the FRF flight directly, it has to be regarded as a combination of air and ground segments. For regulatory issues, the procedures have to be confirmed by ICAO. All developed procedures have to be integrated into the ATM. Therefore the ANSPs' procedures and documentations have to be updated with the FRF ones.

With regard to both the regulatory and certification issues of the air segment, the main conflict with regulations stems from being the pilot out of the loop when the aircraft is under command of the FRF, since the current regulatory framework assumes, explicitly or implicitly, that a pilot is on board to follow the prescribed procedures. Another important issue leading to conflicts with regulations is the loss of communication with ground when the aircraft is under command of the FRF system, since in this situation GSDS is not informed on the aircraft status and evolution of the crisis on-board, and no vital information can be up-linked to the aircraft when necessary. In addition, other aspects considered in the analysis of regulatory issues are Training, Aircraft Maintenance and Security. Regarding training new programmes dealing with 'security avionics' systems' should be developed. Similarly, procedures for handling these special systems should be developed for Aircraft Maintenance Organizations, based on requirements to be included in the regulatory framework.

3.3. FRF Design

In order to enable the implementation of the FRF, the airplane avionics must be fly-by-wire. The design of the FRF has resulted in a set of eight functions and three databases (DB). The functions perform the actions assigned to the FRF to command and control the flight, and communicate with GSDS during the FRF flight of the airplane in emergency. The DB provides the data needed to enable the FRF to perform the calculations for the flight reconfiguration.

The FRF functions are described hereafter:

The **Decision Centre Function (DCF)** shall manage the different FRF capabilities. It shall act like an event controller. It performs the FRF initialization (including built in test), modes management and systems interface management (including update of da-

tabases). The modes management deals with the four FRF modes: START, IDLE, ARMED and ACTIVE, described here below:

- START: power-up of the system;
- IDLE: mode for 'normal' operations of the airplane in absence of security emergencies or threats;
- ARMED: the FRF primary functionality calculates a new flight plan that shall fly the aircraft to a safe landing;
- ACTIVE: the FRF executes the flight plan calculated when in ARMED mode and prepares the aircraft for landing.

The **Health Monitoring System Interface (HMS)** gathers data from systems critical to the operation of the FRF, and performs corrective actions in case of failure in order to ensure continuity of the FRF service. If a failure is critical enough not to be recoverable, the FRF will notify to ground (GSDS) the condition that forced this disengagement. This will give the GSDS the opportunity to consider the best course of action for the given situation.

The **Route Planning and Static Flight Monitoring (RPL)** generates a suitable flight plan to a secure landing airfield. It takes into account the external airfield selection criteria and authorizations and the information coming from the FRF databases regarding commercial routes and airports, terrain, restricted areas and military airports, static and dynamic Prohibited Security Areas and weather.

The **Guidance and Leg Management (GLM)** monitors the flight of the aircraft along the route, continuously evaluating the displacements from the desired path and providing inputs to the autopilot for guidance. It also performs all the operations of leg change and connection.

The **Route Re-planning (RRP)** performs any type of amendment to the flying plan during its execution due to external constraints (e.g., traffic, weather…). Procedures similar to the (RPL) shall be applicable.

The **Dynamic Flight Monitoring (DFM)** consists of different sub-functions that shall be activated during the FRF flight of the airplane:

- A/C Performance Monitoring, in order to provide all the necessary information (fuel consumption, timing information etc.) to FRF to perform a check along the selected path;
- Resolving conflicts with static obstacles, e.g. terrain and PSAs;
- Resolving conflicts with air traffic, performing automatically the TCAS procedures;
- Resolving conflicts with bad weather conditions.

The **External Communication (COM)** produces the information to be exchanged between FRF and the GSDS: FRF Mode, FMS acceptance/rejection of the GSDS flight plan, selected airfield to land, selected flight path, Modified Flight Path and Health Data.

The **Display Management (DSM)** provides the interface between FRF and Display Function. As a general philosophy, in order to respond to terrorist attacks on board, a solution that prevents hijackers to know the real state of the aircraft (engines, trajectory etc) is preferred, only displaying the FRF mode.

Several airplane systems are interfaced by the FRF (Fig. 3). Hence, navigation and surveillance sources, guidance systems and control systems are interfaced by the FRF.

TARMS and EAS are security systems developed in the SAFEE project.

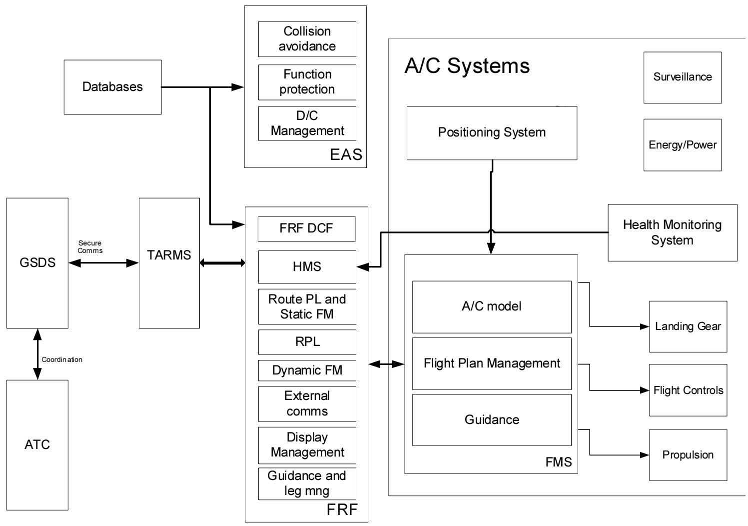


Figure 3. FRF Interfaces (Copyright Isdefe).

The FRF databases are described hereafter.

The **Static and Dynamic Database** stores static data as terrain, obstacles, Prohibited for Security Areas (PSA), civil and military aerodromes and their characteristics to deal with threats, restricted areas, and dynamic data as FPLN and airport selected, weather data, etc.

The **Aircraft Performance Database**, needed to perform the guidance function.

The **Navigation Database**, with Jeppessen plus airliner specific data.

3.4. FRF Safety Assessment

Safety is a requirement "society" poses on air transport. Although air travel is one of the safest forms of transportation, an increase in the number of accidents will not be accepted, not even in a context of growing traffic or emerging threats, such as for instance related to security. Hence the challenge to industry and regulatory agencies to make an already safe system even safer.

FRF provides a solution to a situation with a potentially catastrophic ending caused by the presence of a security threat. When hijacking (or similar threat) occurs on-board an aircraft, the probability of losing the aircraft increases considerably, therefore any action taken to mitigate this possible end result will significantly improve safety. From this point of view, it might not be necessary to design a system to the same level of safety as it is required for current on-board aircraft systems, however the inadvertent activation of the FRF shall be strongly prevented.

It can be demonstrated that such inadvertent activation of the FRF can be dealt with a moderate increase of workload by flight crews and will never have catastrophic consequences. Nevertheless, having a lot of spurious FRFs will not be acceptable by pilots or airlines and will not be sustainable by the ATS. Therefore requirements are necessary to keep this number small enough.

Since the expected number of FRF like scenarios is still to be better assessed, conservative estimates have been performed when imposing safety requirements on the FRF functionalities. Clear show stoppers have not been identified although equipment redundancy and additional design effort might be necessary to reach some of the targets.

While the FRF is in operation there are two main modes that have been assessed throughout this work. The following two paragraphs discuss the feasibility of the functionalities proposed in the different modes from a safety point of view.

In the *ARMED mode*, a number of failures in this functional area could endanger the success of the FRF mission, not only during the calculation of the first FLPN but also in the hypothetical case that the FRF has to recalculate the flight plan and choose a new destination due to unanticipated events (e.g. conflict with traffic, change of threat, weather, etc).

In the *ACTIVE mode*, safety requirements necessary to guarantee a safe landing without a pilot-in-the-loop are also quite rigorous. This includes not only those functions associated to actions performed to configure the airplane for landing but also functions intended to resolve conflicts found on the way to the chosen destination (like traffic or weather).

The following paragraphs discuss the feasibility of the different scenarios from a safety point of view.

1. *Scenario 2: Solution 1 with Datalink Where the FRF Autonomously Chooses a 4D Route*

A large proportion of the safety requirements derived seem feasible for this scenario. Clear show stoppers (safety requirements that definitely cannot be identified) have not been identified. Nevertheless, a number of safety requirements may be very difficult or costly to achieve:

- Information regarding the state of the airport, its runways, its navigation equipment and suitability of weather conditions for landing are of critical importance for the 'blind' landings to be performed by FRF. This poses challenging requirements on availability and quality of the information provided to the FRF at the holding as well as the information provided by ATIS when the FRF is approaching a certain airport and runway. In case of late information that the selected approach and landing can for whatever reason not be performed safely, the FRF has to re-plan an airport, an approach, the runway and possibly even a holding. This process has neither been defined nor assessed in the present work;
- A general issue is the selection of a set of suitable airports where FRF should land the aircraft. These airports on the one hand, should not be too busy, such that procedures necessary for clearing approaches, runways and their neighborhoods are feasible. On the other hand, the navigation equipment of these airports needs to be of very high quality and availability as safe landing of an FRF critically depends on it. Such equipment may be relatively costly for such airports;
- Another general issue is that when overflying cities, nuclear reactors or generally areas where one would not want to have security challenged flights such as FRF is considered as a severe situation (severity class 2) in itself, this poses

challenging requirements to onboard and ground databases regarding the corresponding information.

2. *Scenario 3: Solution 2 Where the Destination Airport is Negotiated with ATC*

The general situation is that the safety requirements for scenario 3 are equally or less difficult to achieve than for scenario 2. This is intuitively clear, as the selected airport and route have been assessed and confirmed by ATC in the negotiation process between FRF and ATC. Nevertheless, the difficult safety requirements for scenario 2 are generally still a challenge.

3. *Scenario 1: Solution 1 Without Datalink, Where the FRF Autonomously Chooses a 4D Route*

Scenario 1 generally seems very difficult to achieve in a manner satisfying safety objectives and requirements. A crucial point on top of the aforementioned requirements, which are here even more difficult to achieve, is that the FRF blindly chooses a destiny airport and approach and is then completely dependent on ATIS for information to confirm that the actual state of the runway, navigation equipment, weather, etcetera allow a safe landing. It seems very difficult to have ATIS contain all necessary information of sufficient quality in a sufficiently timely manner, also because the FRF does not inform about the airport and route it has selected. For the latter reason, the FRF also implies a considerable challenge to ATC.

The work is not complete, even after the safety assessment has been defined and turned over to the system developers responsible for leading the implementation of the FRF. The implementation activities should be continuously monitored to ensure that action is being accomplished, any roadblocks to implementation are removed and the plan accommodates any newly identified gaps.

This safety enhancement process is best accomplished in a step-wise fashion to move to the next level of maturity. Once the initial action plan has been completed, the process should be repeated in order to identify the next safety enhancement actions to be implemented.

4. SOFIA Validation Achievements

4.1. DFS-GAL Validation Exercises

Following the validation cycle adopted by SOFIA, the first validation exercises were run in November 2008. This validation experiment was performed by DFS and GALILEO Avionica (GAL). The validation platform used for the experiment was composed by the ATC simulator from DFS and the ATENA flight simulator from GAL (Fig. 4). Both simulators were connected through a high wide band telephonic line, used to interchange the flight data between both simulators. Solution 1, Flight Plan Without Negotiation, and Solution 2, Flight Re-planning With Negotiation, were tested, involving ATCOs in the ATC simulator and a pilot in the ATENA simulator.

Several objectives for the validation exercise were defined, both with regards to the technical performances of the FRF, and the operational acceptance of the procedures by the ATCOs:

- Test the FRF capacity to negotiate a flight plan;

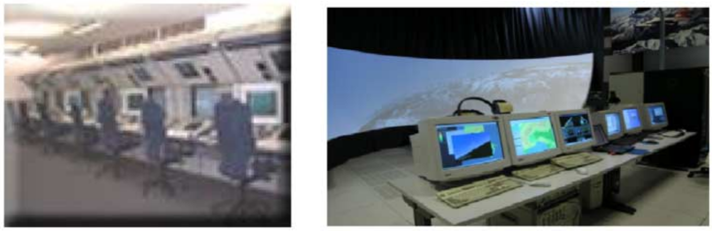


Figure 4. DFS ATC Simulator (left) & GAL ATENA (right) (Copyright DFS and SELEX Galileo).

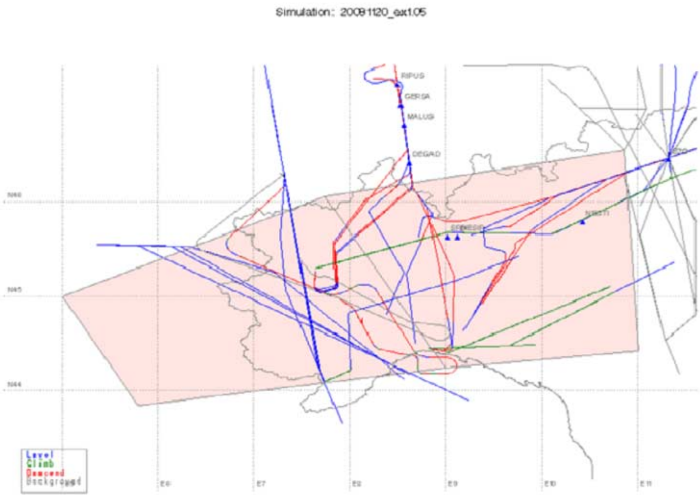


Figure 5. Typical Traffic Sample Used in the DFS-GAL Simulations (Copyright DFS).

- Test the FRF capacity to crosscheck a flight plan received from ground and accept it;
- Test the FRF capacity to execute the accepted flight plan;
- Evaluate the performance of the ATCO when operating in both solutions;
- Assess the impact of each solution on the work load of the ATCO;
- Evaluate which solution is preferred by the ATCO and which provides better performances.

The environment considered comprises the North of Italy, running a flight departing from Sion airport and having the landing scheduled at Milan airport. The flight to be operated by the FRF is inserted in the real flight plan occurred in the area a few days ago, and proposed to the ATCOs as one aircraft more to be managed (Fig. 5).

The flight is operated by the pilot in normal conditions until, in the middle of the flight; the FRF is activated and takes the control of the airplane. Communication is then established between the GSDS (represented by the ATCOs in the exercises) and the FRF, using a data link simulated in the telephonic communication. Once the FRF takes possession of the control and command of the airplane, the pilot remains out of the loop for the rest of the experiment. Depending on the solution tested, the communication between the ATCOs and the FRF includes or not the flight plan negotiation. The destination airport chosen to land the aircraft by the FRF is Turin.

Finally, the three previous operational scenarios are considered in the experiment, resulting in three different exercises carried out by the ATCOs:

- Scenario 1, i.e., flight plan without negotiation and without data link. The flight plan adopted by the FRF is not downloaded to ground as the data link is out of service. This implies the ATCO is not aware of the flight plan the FRF is to execute;
- Scenario 2, i.e., flight plan without negotiation and with data link in service. This implies the ATCO is aware of the FRF intentions as the flight plan is downloaded through data link;
- Scenario 3, i.e., flight plan with negotiation. The ATCO has now the capacity to define the flight plan to be executed by the FRF.

The outcomes from these three exercises demonstrate the technical feasibility of the FRF, being able to manage the solutions (with and without negotiation) without failures. Even more interesting than these conclusions was the assessment of how the human part of the exercises performed. With regards to this, the following conclusions can be stated for each of the scenarios tested:

- Scenario 1, i.e., flight plan without negotiation and without data link. The main concern and problem found by the ATCOS is that they are not aware of the FRF intents. Therefore they are every time reacting to the FRF executions but no medium term prevention is possible. The main risk is the time needed by the ATCO to clear the surrounding airspace and to advise the potential airports were the airplane could land. The FRF provides the ATCO with a time to react between the alert is launched and the FRF starts to execute its flight plan. This time has to be augmented in this scenario to enable good and safe ATCO performance. The negative point is that the increase in time could jeopardize the FRF performance (more fuel consumption). The affected sector has to be closed completely. With regards to the workload, initially, it increases in the affected sector and once this is clear of traffic, the workload increases in the surrounding sectors. Due to the uncertainty introduced in the ATCOs tasks, this scenario jeopardizes the safety of the air traffic system;
- Scenario 2, i.e., flight plan without negotiation and with data link in service. The concern and difficulty in the previous scenario disappear in this second scenario. The ATCOs are aware of the flight plan to be executed and the airport to land at by the FRF. Due to the fact that the flight plan and the landing airport are known, the traffic flow can be handled almost normally. Only the flights to the landing airport must be diverted to other airports. The affected sector does not have to be closed completely. ATCOs considered that safety is kept in the current values;
- Scenario 3, i.e., flight plan with negotiation. The ATCOs generate the flight plan to be executed and the airport to land at by the FRF. This supposes an increase in the ATCO work load not well accepted by them. Due to the fact that the flight plan and the landing airport are known, the traffic flow can be handled almost normally. The only impact is that the flights to the landing airport must be diverted to other airports. The affected sector does not have to be closed completely. ATCOs considered that safety is kept in the current values.

After performing the validation exercises, debriefing sessions were run with the ATCOs who participated in every exercise. Debates were opened and questionnaires

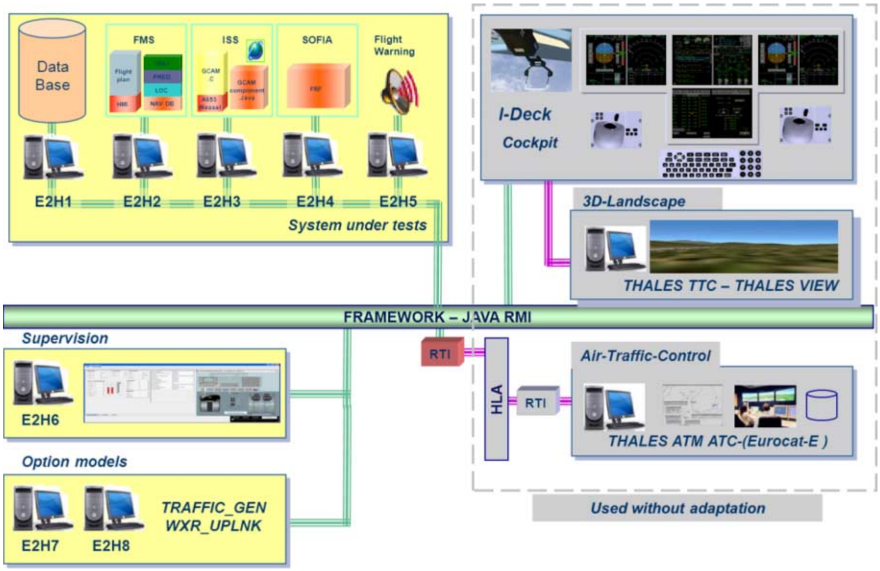


Figure 6. THALES Avionics' Airlab™ Simulator (Copyright THALES Avionics).

were distributed to gather the information needed to evaluate every scenario, the ATCOs preferences, concerns, problems, and in general, all the information that could enable a ranking of the scenarios and solutions tested. After the assessment of the information, it can be concluded that the most preferred scenario for the ATCOS is Scenario 2, followed by Scenario 3. Scenario 1, in the last position, was the only one to be considered as jeopardizing the safety of the air traffic system.

4.2. Validation Exercises

The second validation exercises were performed on a simulator platform by Thales, the THA Airlab™ Simulator (Fig. 6). This simulator controlled SAFEE EAS functions, activated by a basic simulation of SAFEE TARMS in order to activate the SOFIA FRF implementation, shared between existing systems (FMS, ISS, CDS, …) and dedicated SOFIA systems (FRF and associated databases systems).

This selection has been an added value for the SOFIA project to guarantee the continuation of research in FP6 projects. Additionally, SOFIA has joined the EAS and FRF functions. That means the complete security function proposed by SAFEE to protect the aircraft against intended collision into ground is available to design the validation exercises.

The THA validation exercise was focused at the reproduction of FRF_WN scenario: In case the communication between ATCO and the FRF is interrupted, the FRF starts to operate autonomously. In this scenario, new procedures are to be introduced by the ATCO, and different parameters were assessed: creation and execution of the flight plan by FRF and selection of the destination airport by FRF.

This simulation was conducted with two main streams (Fig. 7):

- "Off-Line" Stream: The off-line stream was performed to assess reliability and integrity of the ROUTINGS library by generating safe flight plans. Trajectories were created automatically under constraints by a dedicated tool able to

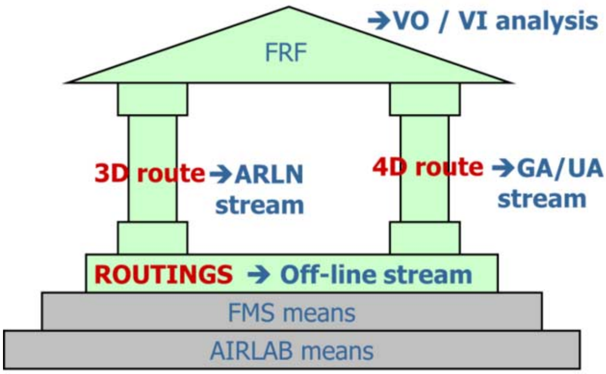


Figure 7. Streams for the Airlab™ Simulation (Copyright THALES Avionics).

configure ROUTINGS input constraints such as a geographical area and local airports. For each couple of airports available in the local area, this automatic process generated a flight plan, which was accepted only when the overall distance was within a selected range (to remove "too-short" and "too-long" trajectories);

- "Routine" and "Emergency" Streams: This run of evaluations comprised 17 simulation executions. For each execution, aircraft flight parameters were recorded, including position, altitude, FRF computed flight plan and FMS computed trajectory. A results analysis was performed off line of all scenarios correctly executed. The elements checked for correctness at run-time by the operator in charge of the evaluation scenario are listed hereafter:
  – The simulation initialization, to ensure the trivial preliminary requirements to run the simulation;
  – The flight mode display (in FMA on PFD), as this information is the description to the crew of the current operating mode of the aircraft. These parameters were used in the SOFIA context to assess that the system in charge of the guidance is correct on executing the correct sub-mode;
  – The execution of the trajectory, in particular, to note the time frames where the aircraft position may be enhanced (versus expected trajectory) and thus ease further off-line analysis;
  – The selected destination computed by the FRF, considering the expected scenario and the currently displayed candidate airport locations;
  – The automatic execution of actions generally handled by the crew (selection of the clearance altitude, activation of the auto-pilot, extensions of flaps and gears…), required to fully matching SOFIA context conditions.

The simulators configuration selected for the SOFIA validation trials facilitated a large scope of validation exercises to perform all the tasks foreseen, with two clear added values with respect to the flight trials: it permits more flexible environments and exercises with no risk to the airspace and enables to check two important tasks like cross-checking of the flight plan and application of the new ATM procedures.

About 140.000 flight hours were simulated to test ROUTINGS operational performances. Correct ROUTINGS behaviour was assessed by a safety check of the gen-

Figure 8. IoA's I-23 Manager Aircraft (Copyright Instytut Lotnictwa (IoA)).

erated route via a certified TAWS functions compliant with FAA and EASA standards (TSO/eTSO c151b), based on the product code delivered by THALES to ACSS T2CAS and T3CAS products lines available for major carriers as Airbus single aisle, long range and wide body families.

The conclusion of this simulation stream was that no ROUTINGS malfunction was noted.

For the second stream, all scenarios designed for SOFIA implementation successfully ended in a stabilized final approach on a candidate airport with no proximity event versus terrain, obstacles, PSA neither weather threats. Thus, the proposed design for the FRF implementation gave very good operational results.

Additionally, no significant discrepancy in the FRF behaviour was measured among the various scenarios. So, the operational expected result of the function was not impacted either by the selected cruise altitude and speed, or the type of terrain under the current flight plan, or the density of the different types of forbidden areas.

4.3. IoA Validation Exercises

Complementary experimental flight tests with real aircraft were carried out within SOFIA. One preliminary requirement was that the FRF software functionality on-board should not jeopardize the A/C airworthiness requirements.

The flight trial undertaken by IoA with the I-23 Manager aircraft (Fig. 8) was focused on the assessment of the FRF when flying in the FRF_WN mode. Therefore, the FRF generated flight plans and executed them. Approach to the runway will be also autonomously performed by the FRF on-board.

In the IoA flight trials, the aircraft was flown automatically but with a pilot onboard for safety reasons, i.e. in case a failure occurs (e.g., malfunction of the FRF) the pilot would resume the control of the aircraft and the FRF functions would be automatically disconnected. In the DAI flight trials, the aircraft was under the full control of the pilot. The FRF acted as a guidance system which was able to send steering signals to the autopilot. The autopilot was also under the full control of the pilot. All normal disconnecting functions were still active. The pilot had also control of the AP-functions that had to be selected manually (e.g. HDG-, NAV- or APR-Mode). Again for safety reasons, in case of a FRF malfunction, the pilot was able to deactivate the autopilot via the normal 'A/P disconnect'– button or the trim switch. These functions were certifica-

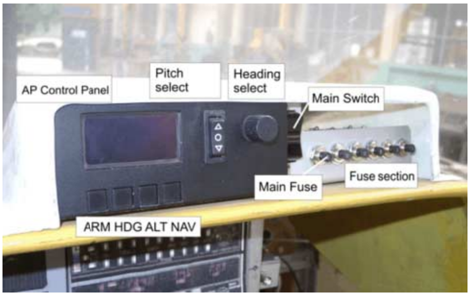


Figure 9. I-23 FRF/AP dedicated (left) and I-23 offset actuators steering cords for FRF (right) (Copyright Instytut Lotnictwa (IoA)).

tion items which should be kept for the flight trials for safety reasons. Modifications were made to the aircraft systems in order to integrate FRF functions (Fig. 9).

During the IoA flight trials some problems appeared:

- Application problems such as stability problems, registry problems or problems with access to some control variables. All these problems were fixed and the flight tests could be performed normally;
- Algorithm problems such as the impossibility of generating a flight plan in certain places or impossibility to start the FRF flight from a position different than the one related to the first waypoint. Again all these problems were solved.

Trials completed by IoA showed that the FRF software worked properly in the fundamental points. The flight plan was calculated correctly and the dynamic trajectory management (WP switching) and the calculation of control parameters for AP were correct.

It was found that other FRF functions such as the calculation of the fuel consumption, time of the flight, changing of the altitude, require more tests on flight simulators or flight trials.

One lesson learned from this exercise was that testing of software during flight test is very demanding and expensive.

4.4. DAI Validation Exercises

The flight trials performed by RDE and DAI were focused on the assessment of the FRF when flying in the FRF_N mode. For this purpose the DA-42 simulator and aircraft are used (Fig. 10). The flight plans were created on ground and transmitted to the aircraft. The aircraft executed the flight plan received from ground and approached to the airport selected by the ATC in an automatic manner.

The objectives of the flight exercises were the following ones:

- Demonstrate only FRF_WN mode;
- Evaluate FRF behaviour inside a simulator prior to flight;
- Only execute those scenarios in flight which were validated successfully in the simulator before.

Figure 10. DA-42 Simulator (left) and Aircraft (right) (Copyright Diamond Aircraft Industry (DAI)).

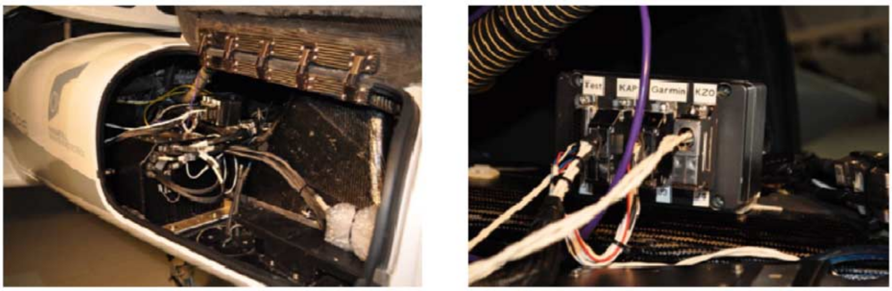


Figure 11. Diamond DA42 Validation Aircraft. Detailed view on the inside of the front compartment (left). Additional SOFIA harness distribution unit (right) (Copyright Diamond Aircraft Industry (DAI)).

For safety reasons additional simulation runs in the DA-42 simulator were added to evaluate the behaviour of the FRF and to find stable areas of the software where FRF can guide the validation aircraft without any risk for crew and aircraft. Depending on the results of the simulation runs it was in the responsibility of DAI and RDE to decide on a permission to flight. Finally the simulation runs were performed correctly and the flight trials took place. Modifications were made to the aircraft systems to enable the integration of the FRF function (Fig. 11).

The different flight trials performed with the DA-42 aircraft showed that trajectories were calculated correctly and could be flown in the way FRF proposed them.

First of all, the trials performed with the DAI-42 aircraft were made to prove that the simulated input of deviation signals led to the correct reaction of the A/P. The flight showed that the qualitative reaction of the A/P was correct. There were quantitative differences between right and left turns noticeable. In left turns the turn rate was less than for standard turns. That led to a higher turn radius which had to be corrected manually. Only little corrections had to be done.

The guidance functionality of FRF in combination with the built-in autopilot showed a fully sufficient precision (horizontal and vertical) for reaching the selected airport.

One important result was that a safe final approach would require additional technical effort to improve position measurement (x, y, and z) as well as functionalities like auto land incl. auto flare which are far away from the functionality of today's autopilots.

During the flight trials all air traffic around the flight test area and especially in the control zone of Bremen Airport that is only a few miles away from the flight test area was monitored by DFS Deutsche Flugsicherung GmbH. Regular air traffic was controlled by the responsible air traffic controllers of the "DFS centre north" located at Bremen Airport. The SOFIA flight which was as well visible in the control centre was additionally monitored by an externally installed air traffic control display.

5. Conclusions

SOFIA, through its research, has reached the following main conclusions:

- SOFIA has defined different procedures for managing aircraft in security emergency situations, being controlled by the Flight Reconfiguration Function (FRF);
- Safety and operability of these procedures were validated and approved by ATCOs;
- SOFIA started the assessment of regulatory and certification frameworks for such security systems not only by the research itself but also through discussions with ICAO, EASA, EUROCONTROL, SESAR and several National CAAs;
- A ground authority and/or system (like a Ground Security Decision System) is needed at European level to:
  - Take legal responsibility of decisions;
  - Generate and track the flight plan for the FRF aircraft;
  - Coordinate with national authorities, ANSP and airports.
- SOFIA moves aviation security a step forward;
- SOFIA opens the door towards the exploration of new application areas for Flight Reconfiguration Function functionalities in fields like:
  - Safety;
  - Small general aviation aircraft;
  - Highly automated systems;
  - UAS;
  - Single crew operations.
- SOFIA validated FRF functions are now available for aircraft operations in the future SESAR environment, specially for 4D trajectory management and trajectory generation.

6. Recommendations for Further Research

The FRF system is proposed as countermeasure to terrorist hostile actions that aim to use the aircraft as a means to affect assets on ground. The affection can be implemented in different ways: crashing the aircraft, using it to propagate biological or chemical agents, or to multiply the effects through the explosion of a mass destruction weapon on-board the aircraft. As a response to this challenge, the SOFIA project developed the FRF system that enables the safe, automatic and autonomous return to

ground of an airplane in the event of hostile actions. To carry out this action, the FRF disables the control and command of the aircraft from the cockpit, creates and executes a new flight plan towards a secure airport and lands the aircraft at it. Regarding the generation of the flight plan to be executed by the FRF, several options are considered in the SOFIA project: The flight plan can be generated on ground (ATC) or onboard a military airplane and transmitted to the aircraft, or created autonomously in the own FRF system. Additionally, the SOFIA project investigates the integration of such solution into different airspace environments: current ATM, ASAS/ADS-B, automation of ground functions, airspace with/without radar coverage, CDM, 4D trajectory negotiation. Finally, the SOFIA project also analyses the impact of the regulatory and certification frameworks on the FRF system and vice-versa; firstly, to constrain the FRF design to such frameworks, and secondly, to propose new procedures and standards to facilitate the technological development.

The FRF system developed in the SOFIA project proposes a solution to one of the biggest challenges of future aviation: to make the aircraft more secure by themselves. But it also introduces some interesting questions that will have to be solved before these systems can start to operate in order to guarantee the security introduced by them. In addition to the technological development, SOFIA considers that further research is necessary in the following areas:

- Integration of the FRF with ACAS to enable the automatic response from FRF to ACAS alerts. Creation and execution of diversion trajectories or simply the execution of the trajectories proposed by the ACAS and ulterior resume of the previous flight plan;
- Collaborative negotiation of the FRF trajectory with other aircraft, in collaboration with ground ATC. The integration of FRF with ADS-B is therefore needed. This would enable a higher integration of the FRF aircraft into the future airspace as defined by SESAR;
- Integration of FRF with advanced surveillance systems like those being proposed by the FLYSAFE and ALICIA projects;
- Explore the application of FRF in other scenarios like safety ones, crew reduction, UAS, very small and personal aviation;
- Need of a ground authority and/or system (GSDS) at European level to:
  - Take legal responsibility of decisions (flight plan, destination airport…);
  - Generate and track the flight plan for the FRF aircraft;
  - Coordinate with national authorities, ANSP and airports.
- Testing of the software during flights test is very demanding and expensive. It is recommended to test the SW in ground simulators and tools well in advance.

Moreover SOFIA poses the following open questions that need of further research to be answered:

- Who is responsible for the management and upgrading of the FRF database, including PSA and airports?
- Who is responsible for uploading and upgrading the FRF database in the airplanes?
- Who is responsible for the designation of the airports capable of dealing with the foreseen threats? and furthermore;

- Who is responsible for designating to what airport an FRF aircraft is to be deviated?
- Who is responsible for the aircraft when it is flown by the FRF system: the airliner, the FRF manufacturer, the nation of the airliner, the nation of the airspace, the nation of the destination airport, EUROCONTROL, the EC, the EDA?
- What is the responsibility of the ATC system, and particularly of the ATCOs, when dealing with an FRF airplane?
- Who is responsible on ground for generating the new flight plan for the FRF aircraft?

Acknowledgment

Juan Alberto Herrería and Jorge Bueno thank the SOFIA Consortium for their great commitment and excellent performance during the project. Without them, the SOFIA project would have not been possible and never a success.

Special thanks also to the European Commission Project Officers, Mr. Jean-Luc Marchand and Mrs. Stephanie Stolz-Douchet. Without their always correct guidance, the SOFIA project could have not been developed in such an adequate way.

References

[1] EC, FP6-2005-AERO-1 Aeronautics and Space Research Work Programme, 01/04/2005.
[2] ACARE, Strategic Research Agenda (SRA) Version 2, October 2004, 2001.
[3] SOFIA consortium, SOFIA Annex I Description of Work, 06/07/2006.
[4] SOFIA consortium, SOFIA D1.2 Definition of the FRF Procedures, 25/04/2007.
[5] SOFIA consortium, SOFIA D1.3 Regulatory and Certification Issues, 19/11/2007.
[6] SOFIA consortium, SOFIA D2.2.2 FRF Final System Safety Assessment (aircraft and airspace levels), 30/05/2008.
[7] SOFIA consortium, SOFIA D2.3 FRF Functions Design, 12/12/2007.
[8] SOFIA consortium, SOFIA D2.4 FRF Databases Requirements, 29/01/2008.
[9] SOFIA consortium, SOFIA D3.2 Platform Adaptation Delivery Report, 22/09/2008.
[10] SOFIA consortium, D3.3 FRF Functions Delivery Report, 22/01/2009.
[11] SOFIA consortium, D3.4 FRF Data System Delivery Report, 22/01/2009.
[12] SOFIA consortium, D4.1 – SOFIA Validation Plan, 29/06/2008.

About the Authors

Juan-Alberto Herreria (10/03/1968, Madrid, Spain) is an Aeronautical Engineer from the Universidad Politecnica de Madrid (Spain) in 1995
He is presently the SOFIA project coordinator
Isdefe, c/Beatriz de Bobadilla, 3
28040 Madrid (Spain)
jherreria@isdefe.es
www.isdefe.es

Jorge Bueno (Tarancon, Spain) holds a Degree in Physics from the Universidad Complutense de Madrid (Spain)
He is working at the Aircraft Operations and on-board devices at ISDEFE, where he is involved in several projects funded by the EU.

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-223

Weather Hazards for Aeronautics – How to Best Respond to This Challenge?

Fabien DEZITTER

Abstract. The European WEZARD project (acronym standing for Weather Hazards for Aeronautics) aims at preparing the future research community in the area of air transport system robustness when it is faced with weather hazards. Its precise objectives are to provide: (i) an interdisciplinary and cross-sector network comprising relevant experts; (ii) a state-of-the-art review of the on-going research actions; (iii) an analysis which will identify the shortcomings, areas for improvements and the type of activity needed to limit the effects of disruptive events; (iv) a set of recommendations and a roadmap validated by the main stakeholders of the aeronautics community.

Keywords. Weather, hazards, icing, volcanic eruptions, particles

1. Background

On April 14th, 2010, the eruption of the Eyjafjallajökull volcano in Iceland and the accompanying cloud of volcanic ash forced most countries in northern Europe to shut their airspace between 15 and 20 April 15, grounded more than 100,000 flights and affected an estimated 10 million travellers. This event revealed to what extent our society and economy rely on the availability of a safe and efficient air transport system and how fragile it still remains when faced with the complexity of atmospheric conditions.

Natural hazards that can severely impact the air transport system are not restricted to the results of volcanic eruptions as they also include other natural hazards involving particles such as icing (Supercooled large droplet, mixed phase and glaciated icing conditions).

The WEZARD project (CSA-SA WEather haZARDs for aeronautics, submitted to the FP7, 4th call) aims to support and contribute to the preparation of future community research in the field of air transport system robustness when it is faced with weather hazards.

2. The Objectives

The detailed objectives of WEZARD are to:

- Set-up an interdisciplinary and cross-sectoral network (comprising expertise from observation and measurement, the aeronautics industry, aircraft operators, network managers, risk management specialists, scientists, etc.);
- Compile a list of the main weather hazards such as hazards which can be spread over very large areas (e.g. volcanic ash clouds) or severe atmospheric conditions (e.g. icing: SLD, mixed phase or glaciated ice conditions);

- Compile the technical consequences of these hazards on the aircraft (failures, damages, etc.);
- Compile an inventory of recent and ongoing R&D activities within relevant areas, and financed through different programmes at EU (FP5/6/7, environment, space/GMES, aeronautics, etc.) as well as at national level, and within relevant institutions;
- Compare, analyse and validate the results of relevant projects and activities in a structured peer review process, and to propose the most mature and relevant new developments for concepts and methodologies, data sources and models, etc. for take-up in risk detection, assessment and risk management. In particular, WEZARD will propose and promote technological solutions for realistic on board integration in term of weight, cost, availability, performance, etc.;
- Develop on this basis a coherent approach to the validation of the relevant input data, models, etc., targeted for the specific purpose of risk management in air transport;
- Finally, provide a R&D roadmap on further R&D and validation activities including priorities, impact analysis and consequence on decision making.

The work will in particular cover hazards which can be spread over very large areas such as volcanic ash clouds or severe atmospheric conditions such as icing (Supercooled Large Droplet (SLD), mixed phase or glaciated ice conditions).

3. Concept and Work Plan

Several different European actors are simultaneously involved in the understanding, decision making and risk assessment process around the crisis management of an event which has a major impact on the Air Traffic System (ATS).

Aircraft manufacturers are required to support the evaluation of the aircraft's operating limits. Meteorological services define where it is safe to fly. The authorities authorise the operators, who are responsible for flying the aircraft, to fly. These same actors are also involved in improving the robustness of the ATS against future occurrences (Fig. 1):

- Aircraft and engine manufacturers will support the evaluation of the aircraft and engine operating limits, develop necessary instrument and equipment, and develop operating and maintenance instructions and relevant training for operators;
- Meteorological services will support the collection of observation data, provide reliable and accurate weather forecast, and broadcast information;
- Authorities will establish safety standard and approved procedures.

To address the different interdependent topics, WEZARD will be structured into 5 work packages (WP):

- WP2 Aircraft Exposure & Robustness will take stock of the knowledge on weather hazards affecting airframe, engine and systems and will identify the needed technology and capability developments pathways;
- WP3 Meteo will compile knowledge on the collection, processing and communication of meteorological data related to weather hazards and will investi-

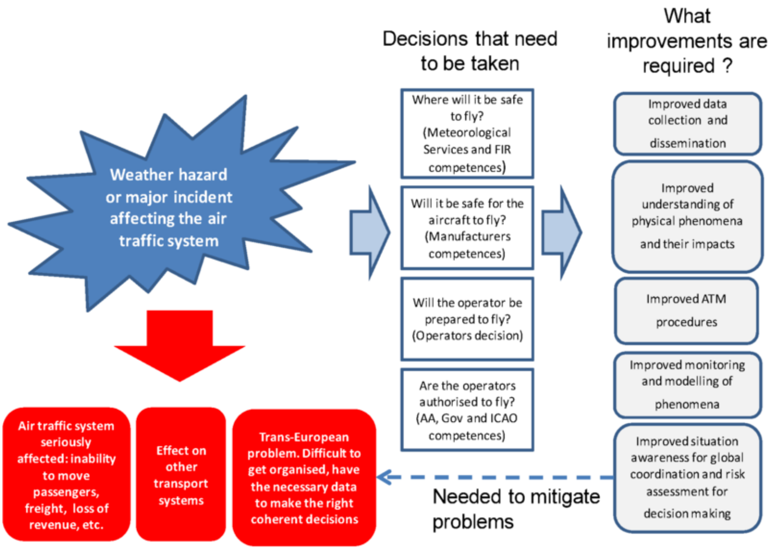


Figure 1. WEZARD project concept – competences' sharing.

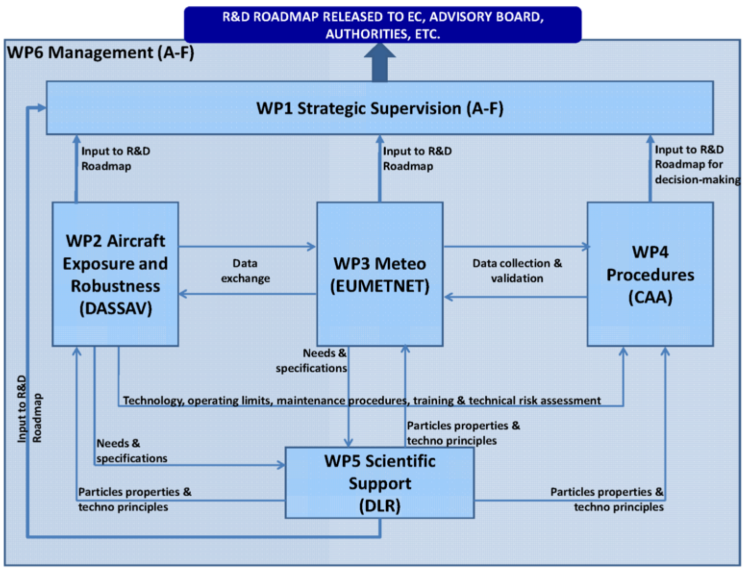


Figure 2. WEZARD Work Breakdown Structure.

gate the needed research on observation, forecasting tools and data assimilation and broadcasting to tackle these extreme aviation atmospheric conditions;

– WP4 Procedures will investigate the existing and needed evolution on safety standard and procedures necessary to ensure safe aircraft operation and to reduce the impact of weather hazards on the air traffic management;
– WP5 Scientific Support will project on the capacity of the scientific community to better understand, observe (onboard sensor, Lidar, Radar, satellites, UAS,

etc.), reproduce and simulate on hazardous particles supporting the assessment performed in WP2, WP3 and WP4;
- WP1 Strategic Supervision will be in charge of ensuring momentum and strategic guidance to the project, consolidating the WP2, WP3, WP4, and WP5 contributions to a common roadmap, coordinating with other international actions of research or working groups.

4. Consortium

The WEZARD consortium has been built to best address above topics and to provide the project with the most relevant and recognised expertises. It is the synergy of 13 partners from 6 countries:

- 4 research centres: ONERA (FR), DLR (DE), EADS IW (DE) and CNR-IMAA (IT);
- 1 meteorological offices network: EUMETNET (BE);
- 1 test facility: DGA (FR);
- 1 civil aviation authority: CAA (UK);
- 6 industrial partners: Boeing Research & Technology (ES), Dassault-Aviation (FR), Thales Avionics (FR), Rolls-Royce (UK), SNECMA (FR), and Airbus (FR).

Furthermore, an Advisory Board gathering a panel of international experts in relevant disciplines and sectors will be set up to provide external advice to the WEZARD consortium on the vision, priorities and directions proposed in the project. The Advisory Board consisting of representatives and key members of major international organisations, working groups, research projects or aircraft operators, its members will actively facilitate and promote links and exchanges with the WEZARD consortium. The Advisory board will be open to new membership all along the project in order to ensure that all relevant skills and expertise are represented.

5. The Expected Results

The results of this work will provide:

- An interdisciplinary and cross-sector network comprising expertise from observation and measurement, aircraft and engines manufacturers, system suppliers, scientists, etc.;
- A state of the art review of the on-going research actions;
- An in-depth analysis which will identify the shortcomings, the areas for improvements and the type of activity needed to develop a safer air transport system and limit the effects of disrupting events;
- A consolidated recommendation and roadmap report validated by the main stakeholders of the aeronautics community.

Finally, the project could contribute to the definition of the next Aeronautic and Air Transport Work Programme by identifying and proposing activities and topics to be investigated. Such a multi-year plan will ensure the sustainability of the WEZARD

network at mid and long term and then will contribute to secure and re-enforce the European expertise on atmospheric hazards.

6. Conclusions

The WEZARD project successfully passed all evaluation thresholds early 2011 and the negotiation for a Grant Agreement has been concluded with the European Commission. The project should start on 1st July 2011 and will last two years.

The first spin-off of the WEZARD project would address mixed phase and glaciated icing conditions: HAIC – High Altitude Ice Crystals.

This proposal for a L2 project will be submitted in the 5th Call of the FP7 Cooperation work programme FP7-Aeronautics and Air Transport (AAT)-2012-RTD-1 and will specifically address the following topic: AAT 2012 3 5 -1 Integrated approach to safe flights under icing condition.

7. Way Forward

Commercial aircraft have been experiencing in-service events while flying in the vicinity of deep convective clouds since at least the early 1990s. Heated probes and engines are the areas of aircraft most prone to mixed phase and glaciated icing threat. In anticipation of regulation changes according to mixed phase and glaciated icing conditions, it becomes necessary to develop the associated Acceptable Means of Compliance and appropriate ice particle detection/awareness technologies, to be fitted on aircraft and able to alert the flight crew when entering in these particular icing conditions.

The technical objectives of the HAIC proposal are:

- Characterise, optimise, enhance and select the most sophisticated cloud microphysics probes to measure mixed phase and glaciated icing conditions during flight tests and to calibrate icing wind tunnels;
- Measure and characterise the microphysical properties of core or near-core regions of deep convective clouds, including cloud liquid and ice water contents, particle size distributions and particle shapes;
- Upgrade European icing wind tunnels to allow reproduction of mixed phase and glaciated icing conditions to allow the European Aeronautical industry to perform equipment qualification;
- Understand and model involved physical phenomena and develop numerical tools to simulate the impact of mixed phase and glaciated icing conditions on aircraft components (mainly engines and probes) for supporting both design and certification phases;
- Develop and validate mixed phase and glaciated icing conditions awareness and detection technologies to alert the crew of flight in these particular icing conditions or to adapt the flight path well in advance in order to avoid such weather conditions.

HAIC should achieve high readiness level (TRL5/6) for technologies and capabilities developed as part of the project.

Acknowledgement

The author and WEZARD consortium would like to acknowledge the European Commission for its support to the CSA-SA WEZARD project (285050).

About the Author

Fabien Dezitter is Leader Technology Product “Icing Phenomena & Protection Systems” at Airbus,
Ice & Rain Protection department (EYAK5)
Airbus – 316, route de Bayonne –
F- 31060 Toulouse cedex 9
fabien.dezitter@airbus.com
www.airbus.com

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-229

Crosswind Reduced Separations for Departure Operations

Lennaert J.P. SPEIJKER
(On behalf of the CREDOS consortium)

Abstract. The NLR Air Transport Safety Institute (ATSI) is involved in development and safety analysis of various concepts to reduce wake vortex separation minima. This paper presents Crosswind Reduced Separations for Departure operations (CREDOS), an EC DG-RTD 6th Framework Programme project, coordinated by EUROCONTROL.

Keywords. Wake vortex, reduced separation, crosswind, departure operations

1. Background

Increases in air traffic over recent years have resulted in congestion at many airports. The need to increase airport capacity is one of the major challenges facing ATM research today. Such an increase could be achieved by reducing the current separation minima while maintaining levels of safety. ICAO separation standards for landing and take-off were implemented in the 1970's to protect an aircraft from the wake turbulence of a preceding aircraft. However research has shown that the transport and persistence of wake vortices are highly dependent on meteorological conditions, so that in many cases the ICAO standards are over-conservative. By developing a full understanding of wake vortex behaviour in all weather categories, separations could be reduced under certain suitable conditions. The FAA investigates Wake Turbulence Mitigations for Arrivals and Departures as part of the FAA Wake Turbulence Research Program. The CREDOS project, which collaborates with the FAA, investigates the operational feasibility of reduced separations by focusing on crosswind. The objectives of CREDOS are [8]:

- To evaluate the feasibility of a Concept of Operations allowing reduced separations for Single Runway Departures under crosswind;
- To provide all stakeholders with the required information to facilitate the implementation of this concept where appropriate in the near-term;
- To increase the body of knowledge concerning wake vortex behaviour during the initial climb phase of flight.

CREDOS delivers an operational concept for reduced separations for crosswind departures as baseline for further implementation at airports where benefits are identified [9], a support package for air traffic controllers and pilots, a database of wake vortices recordings for departures including meteorological conditions from St. Louis and Frankfurt airport, models of wake vortex behaviour in different weather conditions [1,2], as well as methods for wake vortex risk assessment and safety case development [4–6,10].

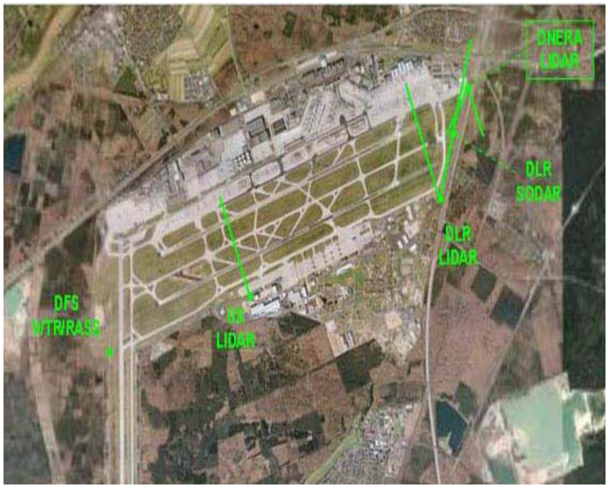


Figure 1. Data measurement campaign at Frankfurt airport.

CREDOS provides a well documented application of the European validation method (E-OCVM) for the new reduced separations concept [11], including a Safety Case, Human Factors Case, Environmental Case, Business Case.

2. What Problems Is CREDOS Addressing?

The ability of the air traffic management network to handle demand is constrained by en-route as well as by airport capacity. With measures to increase en-route capacity producing increasingly significant results, the constraints arising from airport capacity shortfalls require urgent attention. Extending existing airport infrastructure is expensive, requires a long lead time and is often not an option due to environmental considerations. Methods of improving runway throughput using only the existing infrastructure are of increasing interest. The wake turbulence separation minima were introduced by ICAO to ensure that the spacing behind an aircraft of a heavier wake turbulence category is safe for the following aircraft. Applying such minima has proven to be effective in avoiding potentially dangerous wake turbulence encounters but they reduce runway throughput due to the additional distance to be maintained between certain aircraft pairs. CREDOS aims to replace the original, static, and hence often over-conservative, wake turbulence separation minima with lower ones based on actual meteorological conditions, resulting in improved runway throughput.

3. What Are the Expected Benefits?

The CREDOS benefits arise from a temporary increase in runway throughput. This increase occurs only when a lighter aircraft directly follows a heavier one and the crosswind requirements are met… Only in this case is there a potential for reducing the spacing between that aircraft pair compared to the wake turbulence separation that would otherwise have to be applied. The benefits are at maximum during peak periods

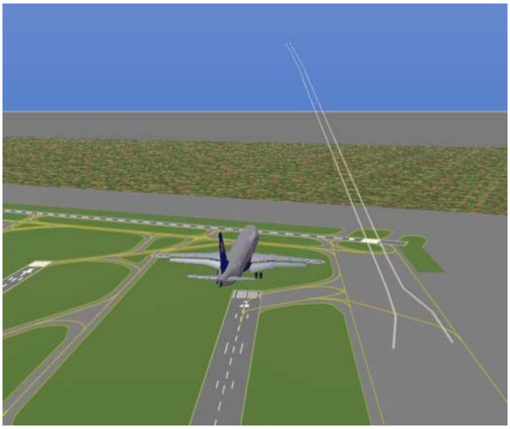


Figure 2. Simulated wake vortices of departing aircraft moving with crosswind.

or when queuing create delays of departing traffic at the runway. An actual change in the declared runway capacity may only be published if a longer period of stable crosswind conditions is forecast. In a queuing situation the benefit for aircraft further down the queue can add up to a substantial reduction of waiting time even if the gain experienced by individual aircraft is limited. This translates into improved punctuality and a reduction of environmental impact. CREDOS' use is not expected to create additional airport slots. The actual benefits are dependent on traffic composition, the usage of the runway and the Standard Instrument Departure (SID) structure. So far only the case of a single independent runway used for departures only has been explored but there is no reason to believe that benefits would not accrue also in a more complex situation.

4. What Meteorological Basis Has CREDOS?

When an aircraft is in motion, wake turbulence forms behind it. The intensity of this turbulence depends on a number of factors, including the mass of the aircraft. Wake turbulence includes various components, the most important of which are wingtip and flap generated vortices and jet-wash. Those vortices are relatively stable and can remain in the air longer after the passage of an aircraft. They represent the primary and most dangerous component of wake turbulence. The hazards of wake turbulence are particularly significant during the landing and take-off phases of flight. Aircraft are in a configuration that creates the strongest vortices while they are also flying at a low speed and low altitude. This leaves little margin for recovery in the event of encountering another aircraft's wake turbulence. The behaviour of the vortices follows a pattern that makes their position predictable if the conditions in the air mass in which they were generated are known precisely enough. The CREDOS concept makes use of the lateral displacement of the vortices behind the generating aircraft as a result of the lateral movement of the air mass concerned (crosswind).

Aircraft take-off into the wind but few take-offs are executed without at least a degree of crosswind component being present. The acceptable crosswind limit is set by the aircraft operator and it depends on a number of factors, including aircraft type. The flight crew may not operate the aircraft on a runway where the prevailing wind conditions exceeded the prescribed limits. Wake vortices generally persist in crosswind con-

ditions, but they also move together with the air mass in which they were generated. Investigations show that the wake vortices and with them the surrounding air mass exhibit a substantial lateral motion well before the crosswind limit is reached for medium or heavy aircraft types. If a lighter aircraft is allowed to take-off behind a heavier one in crosswind conditions with spacing that allows the crosswind to transport the vortices out of the second aircraft's path, the risk of a wake turbulence encounter is practically eliminated. The spacing required to achieve this, results in aircraft being able to take-off closer together than under current wake turbulence separation rules. Runway throughput is increased as a result.

5. What Changes Are Expected?

The CREDOS concept assumes that departures are controlled in an ATS surveillance system environment and that ICAO radar separation minima are applied between aircraft after departure. It is also assumed that the Runway Controller is responsible for establishing the separation minima between departing aircraft. The initial CREDOS concept is focused on accommodating a single independent runway used for departures only with aircraft on the same SID or different SIDs with the first 4 miles identical and, in both cases, also in a straight line.

The idea of CREDOS is simple. Allow crosswind to blow away the vortices and the problem of wake turbulence is gone… While this is true, it must be ensured that the crosswind has actually done its job. Since visualizing the movement of vortices on and in the vicinity of an aerodrome is not practical, an indirect way of ascertaining that they are gone must be found. If the presence of crosswind within a range of prescribed directions and of sufficient strength is ensured, it can be assumed that the vortices are gone… after a certain time. Wind on the aerodrome can be measured, but the higher or the further from the aerodrome, the less accurate the measurement will be. Additional sensors can help but costs set a limit to what can reasonably be done. The capability to accurately measure the crosswind conditions limits the volume of airspace in which the reduced spacing can in fact be applied.

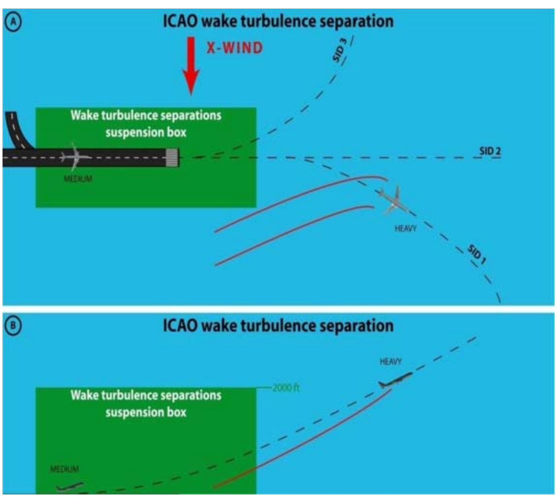


Figure 3. Reduced separation with crosswind.

Figure 4. Aircraft departing, vortices visible behind its wings.

Depending on actually available measuring and forecasting capability, aerodromes using CREDOS will have to designate a volume of airspace around runways in which the reduced spacing can be applied. The volume must have assured wind measurements and must contain, to the extent required and with an appropriate buffer, the tracks of departing aircraft. Wake turbulence separation is safely suspended when required crosswind conditions are met. Outside the airspace volume, conditions are unknown, so there ICAO wake turbulence separation minima apply. Suspension depends on the wind measuring capability, and is terminated when any of the conditions are no longer being met.

6. What Is Next?

The different validation cases [3,7,9,10] have shown that, although there is clear potential from a Business Case, Environmental Case and Human Factors point of view, further work in the area of safety is needed. It is also concluded that the next step for crosswind concept validation should be aimed at performing one or more local implementation cases.

As described earlier, the CREDOS project and hence the concept as it now stands is focused on accommodating a single independent runway used for departures only with aircraft on the same SID or different SIDs with the first 4 miles identical. Neither take-off from an intermediate part of the runway nor super heavy aircraft like the Airbus 380 were considered. Future work will have to explore those areas as well as the case of aircraft on different SIDs and the potential for additional benefits. Concepts for crosswind arrivals have a large potential and will be further investigated in the near future.

References

[1] K. Dengler et al., CREDOS WP2 “Data analysis and wake vortex behaviour modelling”, Final Report, D2-6, 12 October 2009.
[2] K. Dengler, F. Holzäpfel, T. Gerz, A. Wiegele, I. De Visscher, G. Winckelmans, L. Bricteux, H. Fischer and J. Konopka, Crosswind Thresholds Supporting Wake-Vortex-Free Corridors for Departing Aircraft, Meteorological Applications, Article published online: 6 May 2011, DOI: 10.1002/met.261.
[3] L. Garcia and A. Urech, CREDOS Concept Business case, D4-13, 16-11-2009.
[4] S. Kauertz et al., CREDOS WP3 “Risk modelling and risk assessment”, Final Report, D3-11, 25 November 2009.
[5] F. Holzäpfel, J. Kladetzke, S. Amelsberg, H. Lenz, C. Schwarz and I. De Visscher, Aircraft Wake Vortex Scenarios Simulation for TakeOff and Departure, Journal of Aircraft, Volume 46, Number 2, March-April 2009, pp. 713–717.
[6] F. Holzäpfel and, J. Kladetzke, Assessment of Wake Vortex Encounter Probabilities for Crosswind Departure Scenarios, Journal of Aircraft, Volume 48, Number 3, May-June 2011, pp. 812–822.
[7] P. Lubrani and A. Urech, CREDOS Environmental case, D4-14, 27-03-2009.
[8] M.T. Meloni and A. Harvey, Crosswind reduced separations for departure operations: Validation of a concept of operations for the conditional reduction of Wake Turbulence Separation Minima, CREDOS Project in brief, Brochure, 2006.
[9] C. Morgan Chalon, CREDOS Human factors case, D4-10, June 2009.
[10] L.J.P. Speijker, A. Kurlanc and C.J.M. de Jong, CREDOS Preliminary Safety Case, D4-12, 10-11-2009.
[11] L.J.P. Speijker, A. Wennerberg, C. Chalon, P. Lubrani, L. Garcia, O. Desenfans, E. Isambert, D. Mitchell, J. Konopka and A. Scharnweber, CREDOS WP4 “Operational concept and validation”, Final Report, D4-16, 30-11-2009.
[12] A. Wennerberg et al., Final concept of operations description, D4-11, 20-11-2009.

About the Author

Dr.ir. Lennaert J. P. Speijker is Senior R&D Manager at NLR
NLR – Anthony Fokkerweg, 2
NL- 1059 CM Amsterdam, Netherlands
speijker@nlr-atsi.nl
www.nlr-atsi.nl
The public CREDOS deliverables are downlable at:
http://www.eurocontrol.int/eec/credos/public/standard_page/deliverables.html

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-235

Techniques and Tools for Model-Based Analysis of Pilot-Cockpit Interaction

Andreas LÜDTKE and Denis JAVAUX

Abstract. This paper presents the European R&TD "HUMAN" project – European Commission FP7/2007-2013 – the objective of which is to develop a methodology with techniques and prototypical tools supporting the prediction of human errors in ways that are usable and practical for human-centred design of systems operating in complex cockpit environments, in fact a methodology allowing to detect potential pilot more accurately and earlier than today in the design and with reduced efforts. HUMAN is based on a modelling approach. Model- and simulation- based approaches are already well-established for the study, design and manufacture of modern aircraft. HUMAN extends them to the interaction of flight crews with cockpit systems.

Keywords. Pilot-cockpit interaction, cognitive modelling, virtual simulation platform, advanced flight management system, human errors, generic cockpit, crew

1. General Background

The current approach of analysing systems is error prone as well as costly and time-consuming. The HUMAN methodology allows to detect potential pilot errors more accurately and earlier (in the design) and with reduced effort.

The detection of errors is achieved by developing and validating a cognitive model of crew behaviour. Cognitive models are a means to make knowledge about characteristic human capabilities and limitations readily available to designers in an executable form. They have the potential to automate parts of the analysis of human errors because they offer the opportunity to simulate the interaction with cockpit systems under various conditions and to predict cognitive processes like the assessment of situations and the resulting choice of actions including erroneous actions. In this way they can be used as a partial "substitute" for human pilots in early development stages when design changes are still feasible and affordable.

2. Approach

The main research and development work in HUMAN is to produce key innovations on three complementary research dimensions:

- *Cognitive Modelling*: to develop an integrated cognitive crew model able to predict human error categories with regard to deviations from normative activities (Standard Operating Procedure (SOP) and rules of good airmanship).
- *Virtual Simulation Platform*: to develop a high-fidelity virtual simulation platform to execute the cognitive crew model in realistic flight scenarios in order

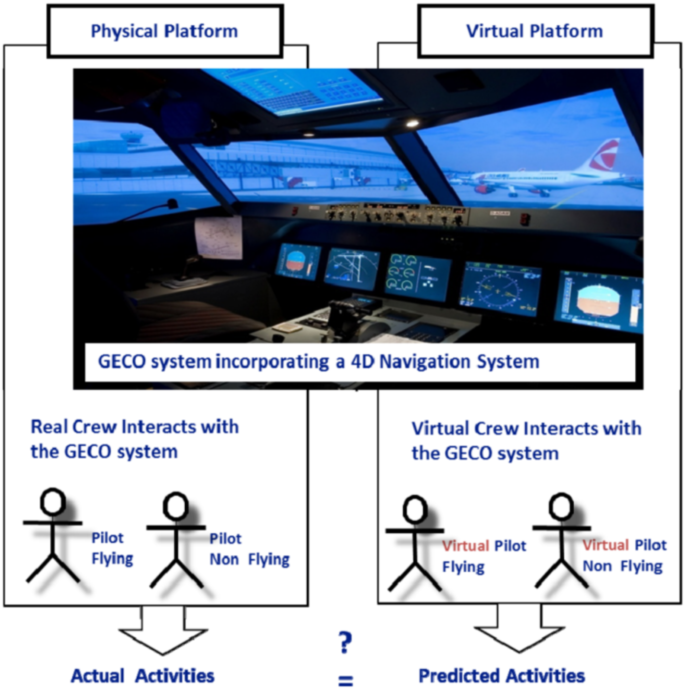


Figure 1. Physical and Virtual Simulation Platforms sharing the same core system.

to analyse the dependencies (including the safety effect of likely pilot errors) between the pilots, a target system in the cockpit, the aircraft and its environment.

- Physical Simulation Platform: to thoroughly investigate pilot behaviour on a physical simulation platform (comprising a full-scale flight simulator) to produce behavioural and cognitive data as a basis for (1) building a detailed knowledge base about cognitive processes leading to deviations from normative activities in the complex dynamic environment of modern aircraft cockpits and for (2) validating and improving the predictions of the cognitive model generated on the virtual simulation platform.

The general idea of the virtual and physical platform is to use the same core system for both in order to ensure the functional equivalence between the two platforms (Fig. 1). This equivalence is a fundamental precondition for validating the cognitive model by producing one the one hand, data sets for predicted crew activities (on the virtual platform) and on the other hand, data sets for actual crew activities (on the physical platform). Predicted and actual crew activities are compared to assess the quality of the model predictions and to derive requirements for model improvements.

The core system is the GEneric COckpit (GECO), a full scale simulator provided by the DLR, one of HUMAN’s partners. In HUMAN it incorporates a target system, the AFMS (Advanced Flight Management System) with flight management functions and crew interface functionality compatible with 4D flight planning and guidance and trajectory negotiation by means of a data link connection. In the project the system is

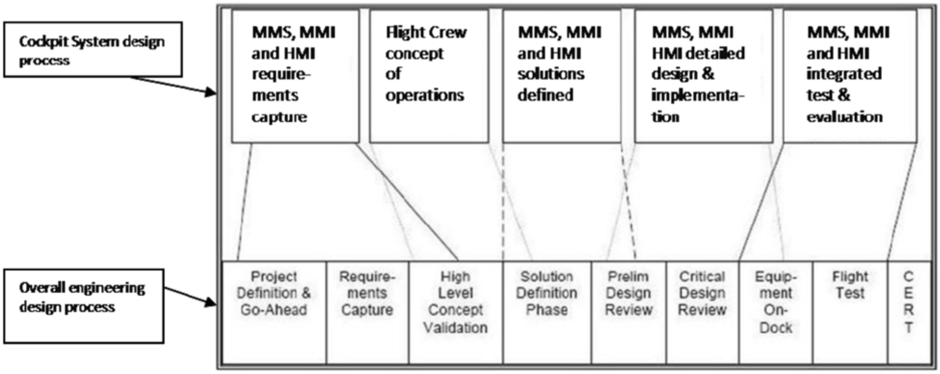


Figure 2. Basic Cockpit System design process shown in relation to overall engineering design process.

extended towards issues pertaining to the future Air Traffic Management context, like trajectory negotiation.

Two experimental cycles have been performed on both platforms to generate a knowledge base on pilot behaviour and to validate and improve the cognitive crew model. In both cycles scenarios that involve the interaction with the AFMS have been flown by 15 airline pilots. The resulting data has been compared with data produced by the cognitive crew model according to gaze behavior [1,2] (gaze distribution, dwell times and scanning behavior), temporal behavior (task completion time and reaction time), multitasking behaviour (switching between flight tasks) and human error [3,4] (learned carelessness and cockpit lockup). Preliminary results can be found in the references given above. The final results have been recently published.

3. Methodology for the Analysis of Human Error

One of the main endeavors of HUMAN, beside the development, testing and tuning of a pilot and crew model, is to make the tools and methodologies developed within the project, including the cognitive model, available to the industry. To do this, we have modeled with our industrial partners the system design process for cockpit systems such as the ones we believe our tools and methodologies could be useful to.

The process followed is similar in its successive steps to that indicated in the ARP 5056 Flight Crew Interface Considerations in the Flight Deck Design Process for Part 25 Aircraft. It however goes beyond ARP 5056, by paying *more explicitly* attention and effort to Man-Machine System (MMS) and Man-Machine Interactions (MMI) design. It also follows elements of ARP 4754 Certifications considerations for Highly-Integrated or Complex Aircraft Systems.

It involves five main, possibly iterative, steps (Fig. 2).

The project delivers four tools:

- Virtual Simulation Platform for simulating crew behavior, predicting pilot errors and testing safety nets;
- Editor for Normative Crew Activities (PED);
- Tool for automatic analysis of display ergonomics (UsabilityAdvisor);
- Tool for Data Analysis.

These tools are allocated to individual steps of the basic cockpit design process. One possibility is certainly to use the cognitive model and the virtual simulation platform to support system development at a very early design stage. The trend in modern aviation is to rely more and more on models of all aircraft systems and structure, and basically, the only missing "system" is the Human element. We believe that a model such as CASCas can play this role and therefore allow the complete virtual simulation of an aircraft and its crew. This should allow test alternative cockpit system designs, including their Human Machine Interfaces (HMI) but also related aspects such as the operational procedures foreseen for the systems.

Acknowledgement

The research leading to these results has received funding from the European Commission Seventh Framework Programme (FP7/2007-2013) under grant agreement n°21988 Project HUMAN.

References

[1] F. Frische, J.-P. Osterloh and A. Lüdtke, Simulating Visual Attention Allocation of Pilots in an Advanced Cockpit Environment. In Modelling and Simulation (MODSIM) World Conference & Expo, 13–15 October 2010, Hampton, Virginia, USA.
[2] F. Frische, J.-P. Osterloh and A. Lüdtke, Modelling and validating pilots' visual attention allocation during the interaction with an Advanced Flight Management Systems. In Proceedings of Human Modelling in Assisted Transportation (HMAT). Milano: Springer Verlag, 2010.
[3] A. Lüdtke and J.-P. Osterloh, Modeling Memory Effects in the Operation of Advanced Flight Management Systems. In Proceedings of the International Conference on Human-Computer Interaction in Aeronautics (HCI-Aero), 3–5 November 2010, Cape Canaveral, Florida, USA.
[4] A. Lüdtke, J.-P. Osterloh, T. Mioch, F. Rister and R. Looije, Cognitive Modelling of Pilot Errors and Error Recovery in Flight Management Tasks. In J. Vanderdonckt, P. Palanque and M. Winkler (eds.), Proceedings of the 7th Working Conference on Human Error, Safety and Systems Development (HESSD 2009), LNCS 5962. Springer Verlag 2010.

About the Authors

Andreas Lüdtke
OFFIS Institute for Information Technology
Escherweg 2
D-26127 Oldenburg, Germany
luedtke@offis.de
www.offis.de

Denis Javaux
Next Step Solutions
Rue Daussoigne-Mehul 20
B-4020 Liège, Belgium
denis.javaux@skynet.be

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-239

SUPRA – Simulation of Upset Recovery in Aviation

Eric GROEN and Lars FUCKE

Abstract. Loss of control in flight is the leading cause of fatal accidents in commercial aviation today. Due to infrequent nature of upset events in operations, many commercial pilots have never experienced such a situation. So, aircrews may not be proficient in dealing with such events, a fact which calls for specific upset recovery training. For many reasons, ground-based simulation of these extreme conditions might be the only viable option for effective and cost-efficient pilot instruction. Due to the lack of validated aircraft models outside the normal operating envelope current flight simulators do not adequately represent aircraft behavior at the edge of the envelope. The European FP7 project called "SUPRA" – Simulation of UPset Recovery in Aviation – aims at filling this gap by extending dynamic simulation models beyond the current state-of-the-art.

Keywords. Loss of control in flight, upset recovery training aid, motion perception model, motion simulators, upset scenarios, types of upset regimes

1. Introduction

Loss of control in flight (LOC-I) is the leading cause of fatal accidents in commercial aviation today [1] (see Fig. 1 for most recent statistics). In the course of loss of control events, the aircraft often enters into unusual attitudes or stalls, also called upsets. To prevent or timely exit a loss of control situation it is essential that the flight crew rapidly recognizes the condition, initiates recovery action and follows appropriate recovery procedures. However, upsets are infrequent events in today's operations and many commercial pilots have never experienced such a situation. Hence there is international consent that understanding, recognition and recovery from unusual attitudes and stalls need improvement.

The FAA-Industry Airplane Upset Recovery Training Aid (URTA) was an important step, using full flight simulators for demonstration and training of recovery techniques [2]. Due to the lack of validated aircraft models outside the normal operating envelope, the URTA remains limited to maneuvers within this envelope. However, as analysis of LOC-I accidents shows [3], upset events take aircraft outside the normal envelope. Current flight simulators are not equipped to simulate these upset events in a reliable way, not only because of limitations of the aircraft model, but also because conventional hexapod-type moving bases do not generate the representative motion cues. These technological shortfalls justify investing R&D effort into modeling and simulation of these flight regimes.

The project SUPRA – Simulation of Upset Recovery in Aviation – www.supra.aero – aims at extending aerodynamic models and motion cueing solutions beyond the current state of the art. The project is investigating the feasibility of conducting advanced upset recovery simulation on hexapod-type as well as on experimental simulators, such as the centrifuge-based DESDEMONA-device in the Netherlands.

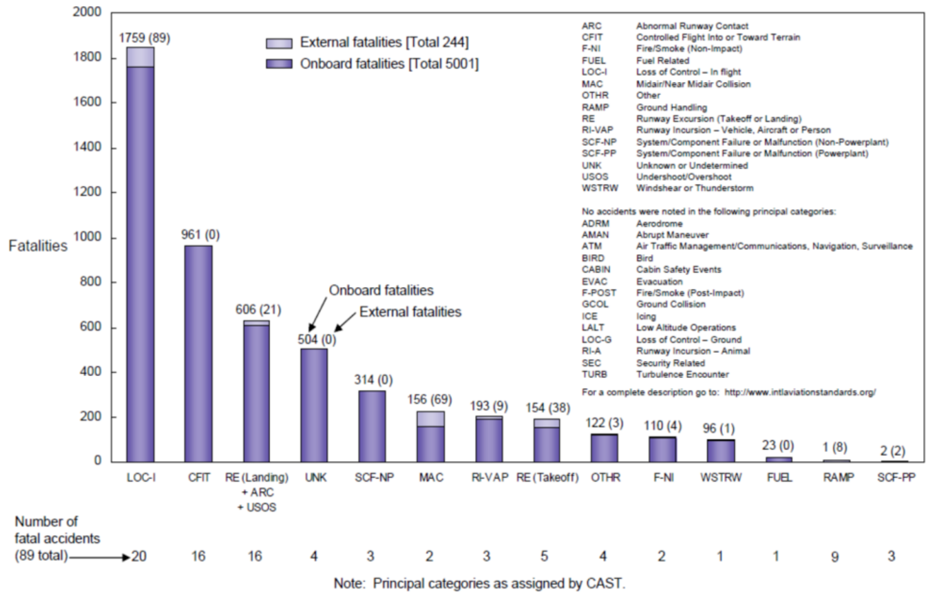


Figure 1. Worldwide statistics of commercial jet airplane accidents by cause, 2000–2009 [1].

2. The Project at a Glance

With its ten partnering organizations from the Netherlands (Netherlands Organisation for Applied Research, TNO; National Aerospace Laboratory, NLR; Desdemona Ltd., DES), Austria (AMST Systemtechnik), Germany (Max Planck Institute, MPS), Spain (Boeing Research & Technology Europe, BR&T-E), Russia (Central Aerohydrodynamic Institute, TsAGI; Gromov Flight Research Institute, GFRI; Dynamika, CSTS) and the United Kingdom (De Montfort University, DMU), SUPRA is a true international effort. In addition to the organizations participating directly in the project, SUPRA is supported by an external group of experts providing guidance throughout the project lifetime. The group is to ensure stakeholder buy-in and acceptance; it consists of test and airline pilots, representatives from aircraft manufacturers, pilot associations, training organizations and simulation and modeling experts. Several members of the expert group as well as researchers from within the project are represented in other activities in the field, e.g. the Royal Aeronautical Society's (RAeS) International Committee on Aviation Training in Extended Envelopes (ICATEE), ensuring coordination with relevant endeavors in the area of upset recovery simulation. The official start of the EUR 4.9 million project was September 2009. The project duration is 3 years, and final conclusions of the SUPRA project will be available by end of August 2012.

3. Technical Objectives

Goal of the SUPRA project is to develop high-fidelity, thus effective concepts of ground-based upset simulation to aid pilot training in such flight regimes and further

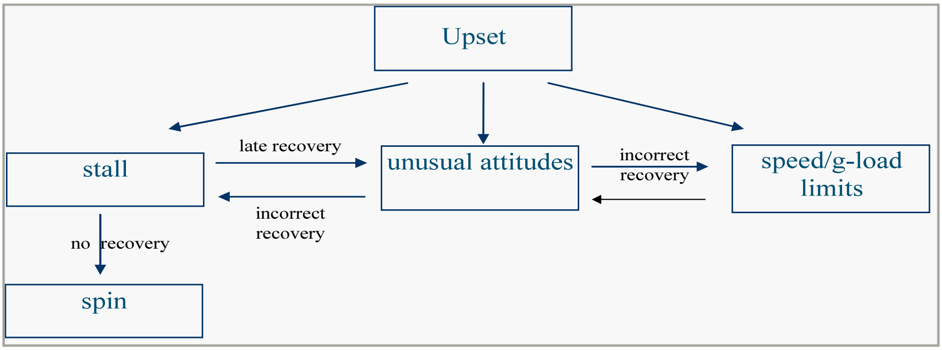


Figure 2. Types of upset regimes.

reduce the accident rates associated with today's LOC-I events. In order to achieve this goal, SUPRA has set the following detailed technical objectives:

- Establish a set of SUPRA relevant upset scenarios, i.e. scenarios typically associated with LOC-I accidents or incidents;
- Development of a representative aerodynamics model covering upset regimes outside the normal envelope, i.e. approach to stall, stall departure and possibly spin;
- Extension of pilot perception models to better understand the motion environments encountered during upset simulation;
- Development of advanced motion cueing solutions for hexapod-type and centrifuge-type motion simulators;
- Development of guidance material detailing technical requirements for the conduct of improved upset simulation.

4. Approach

SUPRA is systematically addressing the technical objectives set at the get-go of the project and is involving the external expert group whenever a broad consensus has to be reached in order to make sure the SUPRA decisions are applicable across the industry. Involvement of the expert group was essential when determining which upset scenarios to focus on within the project.

4.1. Upset Scenarios

The term upset comprises a multitude of flight regimes not typically encountered during normal flight operations of commercial transport airplanes. As shown in Fig. 2, stalls, including spins, exceeding of maximum airspeed, Mach number or structural limits as well as flight at unusual attitudes (pitch angles in excess of +25 / –10deg, bank angles above 45deg) are typically called upsets. Figure 2 also visualizes the dynamic nature of upset events: depending on the flight crew actions an upset situation can quickly evolve from one type into another. In cooperation with the external expert group it was decided early on in the project that upset recovery and awareness training should provide subject pilots with the necessary tools to recover at ideally any point in

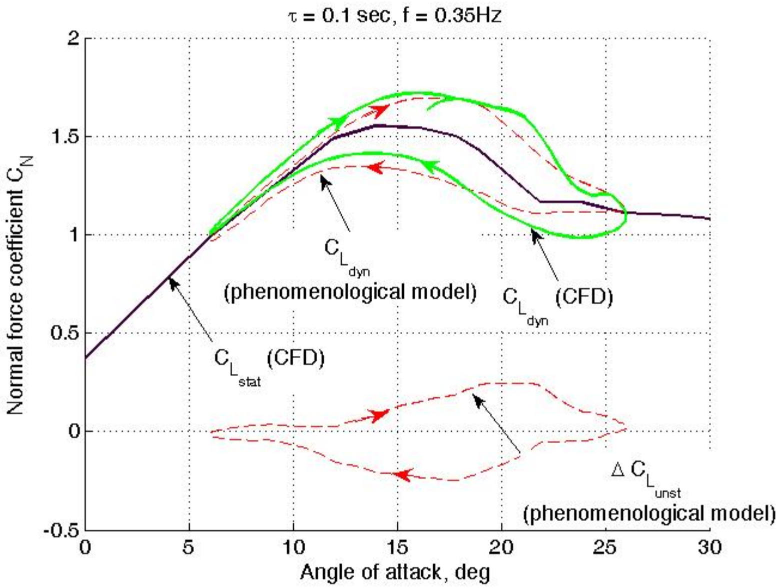


Figure 3. Dynamic hysteresis: lifting coefficient as predicted by steady-state CFD (CL stat), unsteady CFD methods (CL dyn) and phenomenological model.

time of a dynamically evolving upset event. Consequently SUPRA decided to build upon the unusual attitude scenarios from the Industry Upset Recovery Training Aid and extend those by approach to stall and stall scenarios, including fully developed spin for demonstration purposes [4].

4.2. Aerodynamic Modeling

SUPRA is going new ways here. Using a phenomenological approach previously applied successfully to similar problems with military aircraft, supported by wind tunnel and unsteady Computational Fluid Dynamics (CFD) methods, SUPRA is creating a reconfigurable, aircraft class-specific model [5]. Other than previous efforts in the field which have developed type-specific models, SUPRA chose to develop two class-specific models at a more generic level: a medium-sized airplane in T-tail configuration with engines on the tail and a large-sized airplane with conventional tail and two engines under the wing. The model can be reconfigured rapidly to represent either aircraft class and/or different stall departure characteristics. Figure 3 gives an idea of the unsteady effects covered by the phenomenological model. Other important effects include non-linear behavior for high angles of attack and side-slip as well lateral-directional instabilities.

4.3. Motion Perception Model and Advanced Cueing Solutions

SUPRA is making use of a multitude of experimental facilities: the hexapod-type flight simulators PSPK-102 (TsAGI) and GRACE (NLR) as well as the centrifuge-type simulator DESDEMONA (Fig. 4). On the one hand the project is to demonstrate that im-

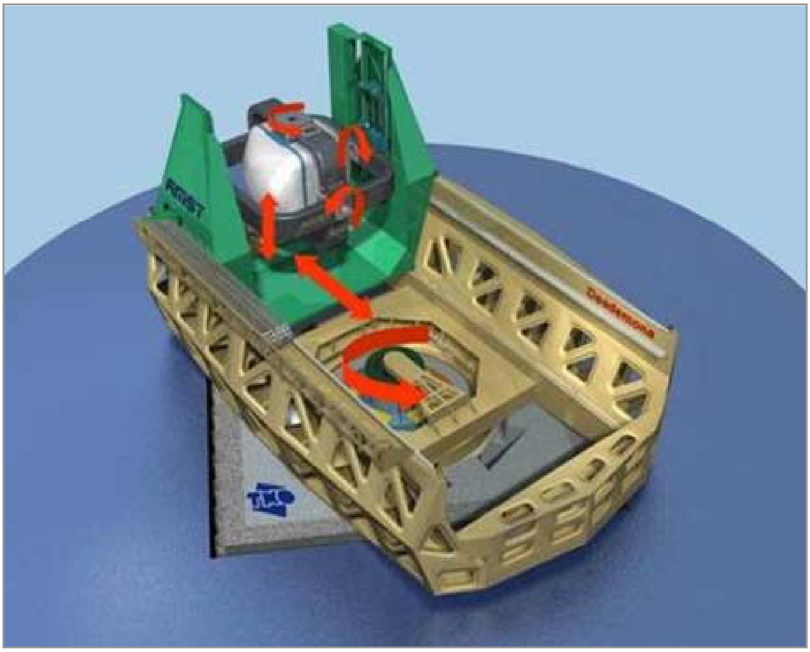


Figure 4. The six degrees-of-freedom centrifuge-type motion simulator DESDEMONA (TNO/AMST).

proved/optimized motion cueing is possible on standard hexapod platforms, on the other hand it is to explore the feasibility of upset simulation on advanced platforms. Both objectives require developing optimized motion cueing solutions taking into account characteristics of the respective platforms as well as scenario-dependent motion profiles. More specifically the task of motion cueing can be described as reproducing the motion cues important to the pilot while minimizing false cues, i.e. cues that are simulation artifacts and would not exist in real flight. The task requires a detailed understanding of pilot motion perception in the specific upset environments which can include elevated levels of sustained G-loads and high rotational rates. Further, the specifics of centrifuge-type simulators bring about the possibility of generating sustained forces but, at the same time, may introduce additional false cues such as Coriolis-forces. SUPRA has identified a number of knowledge gaps which have been directly addressed performing psychophysical experiments on the above mentioned platforms [6] and on MPS's robotic CyberMotion Simulator. Additionally, GFRI's Tu-154 flying test bed FACT (Fig. 5) is at SUPRA's disposal to perform experiments in real flight. To complete the picture SUPRA is developing an integrated motion perception model fusing traditional, describing function based ways of modeling perception with Bayesian, i.e. probabilistic approaches.

5. Evaluation of the "SUPRA" Concepts

Evaluation of the concepts developed by SUPRA naturally is not a trivial task as direct comparison to real flight, due to safety reasons, is not practical except for a very li-

Figure 5. Flight deck of the FACT flying test bed.

mited sub-set of the upset situations. Hence, evaluation of the project success is mainly based on expert acceptability. SUPRA can draw upon a number of assets to perform this task. From within the project GFRI test pilots, familiar with upset situations on commercial transports are available. From outside the project, SUPRA is making use of pilots of the expert group. In preparation of the evaluation task all SUPRA components, i.e. optimized motion cueing algorithms and the advanced flight dynamics model have been integrated into the simulators involved into the evaluation task. Flight deck characteristics including displays and controls have been brought to a common generic commercial transport standard which facilitates comparison of evaluation results between simulators. Figure 6 is showing the DESDEMONA simulator configured in commercial airliner lay-out.

6. Conclusion

SUPRA is addressing a top-level need of commercial aviation safety: Loss of control in flight. Underlined by recent high profile events, there is broad consent in the aviation community that awareness and training of upset prevention and recovery needs improvement globally. SUPRA is developing detailed guidelines to follow in order to perform effective upset recovery simulation on current training-type simulators as well as advanced platforms capable of reproducing sustained G-forces. The project is coordinating its activities with other international efforts in the field as well as keeping the regulators involved. An international expert group is ensuring acceptability to the operators and training organisations.

Figure 6. DESDEMONA simulator in SUPRA commercial airliner lay-out.

References

[1] Boeing Commercial Airplanes, Statistical Summary of Commercial Jet Airplane Accidents, Worldwide Operations 1959–2009.

[2] Industry Airplane Upset Recovery Training Aid Team, Airplane Upset Recovery Training Aid, Rev. 2, November 2008.

[3] K. Cunningham, J. Foster, G. Shah, E. Stewart and R. Ventura, Simulation Study of Flap Effects on a Commercial Transport Airplane in Upset Conditions, AIAA-2005-5908, AIAA AFM Conference and Exhibit, San Francisco, CA, August 15–18, 2005.

[4] L. Fucke, V. Biryukov, M. Grigoriev, V. Rogozin, E. Groen, M. Wentink, J. Field, B. Soemarwoto, N. Abramov, M. Goman and A. Khrabrov, Developing scenarios for research into upset recovery simulation, AIAA Modeling and Simulation Technologies Conference, Toronto (ON), August 2010.

[5] M. Goman, A. Khrabrov and B. Soemarwoto, Aerodynamic model development for simulation of upset recovery of transport airplane, Aerodynamics Conference, Royal Aeronautical Society, London (UK), July 27–28, 2010.

[6] E. Groen and W. Ledegang, Centrifuge-based simulation of unusual attitude recovery in Desdemona. Journal of Aircraft (accepted).

About the Authors

Dr Eric Groen, Senior Scientist – Aerospace Physiologist – Scientific Coordinator of the SUPRA project
TNO – Kampweg 5 – NL- 3769 DE Soesterberg, The Netherlands
Tel.: +31 (0)888665926
eric.groen@tno.nl

Lars Fucke, Senior Engineer – Safety R&D – SUPRA Dissemination and Exploitation Lead
Boeing Research and Technology Europe
Avenida Sur del Aeropuerto de Barajas, 38, Edif. 4 – pl. 4ª
28042 Madrid, Spain
Tel.: +34 91 768 84 34
Lars.fucke@boeing.com

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-246

"ALICIA": All Conditions Operations and Innovative Cockpit Infrastructure

Linda NAPOLETANO and Daniel DREYER

Abstract. Low clouds and poor visibility are the most disruptive factors for aviation. So, considering the expected growth of the air traffic over the next decades, it is vital to reduce the impact of difficult weather conditions. The European FP7 project called "ALICIA" – All conditions operations and Innovative Cockpit Infrastructure – here below described aims at developing new and scalable cockpit applications which can extend aircraft operations in degraded conditions and at providing the critical building blocks necessary to reduce delays in Europe associated with bad weather. The final goal is to achieve All Conditions Operations (ACO) allowing aircraft to fly with the same safety and performance in almost every conditions.

Keywords. All conditions operations, head-up display, head mounted display, cockpit, synthetic vision system, enhanced vision system, combined vision system, taxiing, human machine interface (HMI)

1. Introduction

Today, low visibility in the critical phases of the flight is one of the most disruptive factors in European aviation, and causes about 50% of arrival delays [1].

In 2007 alone, at London's airports, more than 57,000 flights were delayed because of the weather. Delays cost about 1 billion Euros per year. Air traffic in Europe is expected to grow steadily over the next decade, and to support this growth, it is vital to increase the efficiency of the air transportation system, and reducing the impact of difficult weather conditions.

ALICIA is an R&D project co-funded by the European Commission under the Seventh Framework, with the aim of developing new and scalable cockpit applications which can extend aircraft operations in degraded conditions, and provide the critical building blocks necessary to reduce delays in Europe associated with bad weather.

The All Conditions Operations (ACO) research aims at enabling a robust worldwide operations capability allowing aircraft to use airports with less capable ground based approach aids, and enhancing aircraft autonomy such as the anticipation and avoidance of adverse weather in-flight or on the ground. Concepts such as ACO underpin the rationale for the new cockpit architecture, which integrates technologies and applications for both fixed- and rotary-wing aircraft types.

Information about weather and surrounding air traffic, from both ground and airborne sources, will be presented on touch screens and "head-up" displays, 3D audio will enable the crew to make quick and effective decisions, while dockable displays will support pre-flight activities.

ALICIA's goal is to achieve effective All Conditions Operations: this means allowing aircraft to fly with the same safety and performance in almost every weather

condition with solutions envisaged to cover every phase of the flight, from taxiing, to cruising, approaching and landing.

These advances will optimise crew workload whilst enhancing safety and improving crew situational awareness. The development of solutions in ALICIA takes into account the different conditions in which different aircraft are flown, and the specific needs of helicopter crews and missions (e.g. replacing the Head Up Displays used in commercial aircraft with Head Mounted Displays).

2. The Project

The ALICIA project started in 2009 and will last until 2013. The project directly addresses the Vision 2020 goal of improved time efficiency in the air transportation system by developing new cockpit systems that can deliver significantly more aircraft movements than is possible today. ALICIA will couple the latest thinking in air traffic management (SESAR) with new cockpit concepts capable of providing improved mission performance whilst also enhancing situation awareness. Thus, the two key areas of technological advance will be an All Conditions Operations (ACO) system capable of delivering robust worldwide operations capability, allowing aircraft to use airports with less capable ground based approach aids, in a wider range of degraded flight conditions. The second key area of technological advance is the new cockpit architecture facilitating the introduction of new cockpit technologies and applications capable of driving down crew workload whilst enhancing safety and improving crew situational awareness. The rationale for the new cockpit architecture is borne of the certainty that within the next decade the cockpit design will be stressed by the introduction of a series of new concepts such as ACO and those being developed within the SESAR programme.

The two overarching project objectives are:

- Development of an ACO capability to reduce weather-related delays by 20%;
- Development of a new cockpit architecture facilitating the introduction of new technologies and applications (Fig. 1).

The ALICIA programme provides an opportunity for many key stakeholders in Europe to work together towards a new approach to cockpit design. The application focus within the project will be All Conditions Operations because the technology integration implicit in the implementation of this system will challenge the cockpit design. However, All Conditions Operations is just one element of a diverse range of new systems that will arrive in the next generation cockpit and the cockpit architecture must be flexible enough to support this. Accordingly, within ALICIA, new core concepts applicable to all new flight-decks will be defined that facilitate the efficient introduction of a broad and expanding range of operational requirements, whilst achieving the lowest through life cost.

The utility and scalability of the new concept will be demonstrated using simulation/synthetic environments and bench testing to illustrate the feasibility of highly integrated on board functions performing:

- Strategic Surveillance of the Aircraft Environment;
- Enhanced Navigation;
- Robust Worldwide Operations in demanding Flight Conditions.

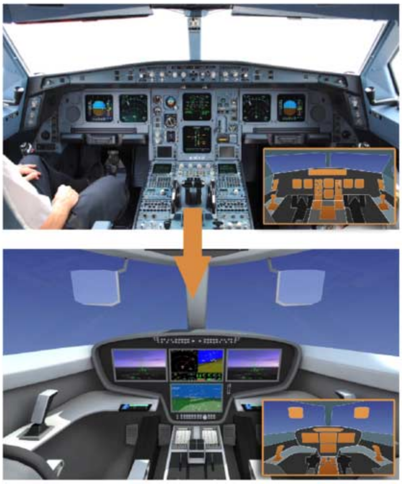


Figure 1. New cockpit architecture.

The project began by defining operational and technological requirements of the cockpit of the future, and conducting a thorough recognition of existing and emerging technologies (Requirements Capture, Concept Generation, Technology Selection/ Refinement).

Selected technologies will be integrated in the design of new cockpit prototypes, which will finally be evaluated through simulators (Application Development, Evaluation in Cockpit Simulators).

3. Results

ALICIA will make advances in the design of next generation cockpits using an approach that embraces the principles of increased commonality across multiple aircraft types. This aims at contributing to increase the re-use of European technology creating further competitive advantage whilst reducing time to market. Some of the key innovations pursued within ALICIA include:

- Robust management of flight phases near and on the ground;
- Enhanced vision system and synthetic imagery;
- Holistic approach to HMI design and integration;
- Integration with the future airspace infrastructure;
- Enhanced use of synthetic environments to support concept validation and product certification;
- Novel display, control and audio concepts, e.g. head mounted displays, direct voice input, audio environment including 3D audio, large area/high resolution displays;
- Improved sensor technologies supporting all environment capabilities;
- High integrity architectures and databases;
- Enhanced navigation techniques.

The operational gains obtained include the decision height below 200 feet for all equipped aircraft on almost all runways/landing sites in low visibility/bad weather conditions; more autonomous taxiing capability in low visibility/bad weather conditions; and optimized flight efficiency and safety by providing an accurate picture of the weather situation around the aircraft and along its intended trajectory.

4. The ALICIA Scenarios

Although the ALICIA cockpit concept is still at an early phase of design definition, a number of candidate HMI philosophies and supporting technologies have been identified as strong contenders for the critical components that form the foundations for the design concept.

In support of operations in degraded visual environments a greater use of computer generated graphics, to present a picture of the external environment to the crew is proposed. This concept is typically referred to as Equivalent Visual Operations (EVO) and is endorsed through existing technologies such as Synthetic Vision System (SVS), Enhanced Vision System (EVS) and Combined Vision System (CVS) although there are currently limitations to the operational use of these technologies.

It is anticipated that the future for enhanced Equivalent Visual Operations will require the extended use of Head Up Display and Head Mounted Display technologies. These display mediums are capable of providing the crew with critical flight information, and can present terrain and threat information using computer generated graphical formats using techniques such as conformal symbology.

In the next paragraphs we are providing some high level scenarios suggesting possible impact of the ALICIA flight deck.

4.1. Flight Planning

Dockable displays can be used for flight planning in an office or at home. Routes, weather forecast and all aspects of flight preparation can be generated before pilots' arrival at the airport. This allows them to become familiar with the new route. Consequently, this may lead to quicker procedures on board of the aircraft, which could have a positive influence on delays (Fig. 2).

4.2. Taxiing

Taxi operations now rely mostly on direct vision through the windscreen. In low visibility conditions, pilots cannot easily identify obstacles and navigate on taxiway and runway. Another consequence of traffic growth is increased risk of runway incursion. Information from the aircraft's navigation and positioning system, digital maps of the airport area and brake & steering cues, can be presented on a Head-Up Display (HUD), a transparent surface in the pilot's sightline through the forward cockpit window (Fig. 3).

4.3. Cruising

While flying towards bad weather real time information is presented to the crew that allows them to manage a large quantity of data coming from different sources, clearly

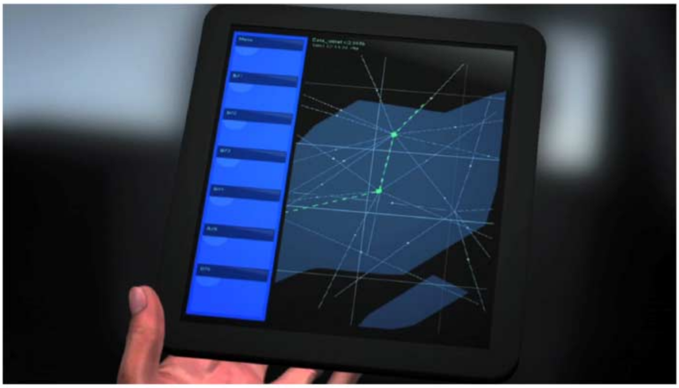


Figure 2. Simulation of a dockable display.

Figure 3. Simulation of Head-up Display.

selecting, at any time, the data that are the most relevant for the crew. The system presents to the crew the weather conditions around the aircraft, and detects potential threats. Weather data are collected from different sources and tailored to the aircraft's request and specific needs. The crew makes quick decisions based on these data, and re-plans the flight when necessary. A new, safer route is calculated by the onboard computer, and sent to ground control for approval before being selected. While the pilot looks through the display to see the outside world, the system can effectively make up for lost visibility, allowing the pilot to perceive the same position clues he would ordinarily receive by looking outside (Fig. 4).

4.4. Landing

The landing phase is particularly critical in bad weather conditions. As the aircraft approaches ground with low visibility, the pilot must be aware of potential obstacles such as high buildings, or wires. A Synthetic Vision System can be displayed on the cockpit's Head-Up Display. It utilizes precise navigation sensor inputs, and data from terrain, obstacle and runway databases to generate a synthetic, three dimensional view of

Figure 4. Interactive re-planning of flight path due to bad weather on a touch screen.

Figure 5. SVS as seen through a HUD.

the external aircraft environment, leading the pilot to land just as safely as he would with perfect visibility (Fig. 5).

4.5. Helicopters

Helicopters pose specific requirements as they are often flown in extreme conditions, in particular when servicing offshore platforms, or when used for rescue operations during natural disasters. The solutions envisaged for commercial airplanes must be adapted to the specific conditions found on a helicopter. For example, Head-Up Displays are replaced by Head-Mounted Displays, which give the same visual information with the necessary stability and allow the pilots to see the information presented even when they are not looking through the front windscreen. Active stick controls allow the pilot to have a sensory feedback about the forces applied on the aircraft. In addition 3D Audio can effectively help pilots communicating with ground stations and avoiding obstacles (Fig. 6).

ALICIA will demonstrate the utility and scalability of the new concepts using simulation/synthetic environments and bench testing to illustrate the feasibility of highly integrated on-board functions performing strategic surveillance of the aircraft environment, enhanced navigation and operations in demanding flight conditions.

Figure 6. Example of a Head Mounted Display.

5. The Consortium

To achieve its goals, ALICIA brings together all the key players in European avionics: 19 industries, 7 research centers, 11 small and medium enterprises, 5 universities are cooperating, preparing the future of European Air Transportation. Moreover, ALICIA involves end user representatives through the External Expert Advisory Group, from the early stages and during the life of the project to deliver operational and practical feedback to ALICIA's Work Packages. This aims at ensuring that the developed systems will meet the stakeholders' expectations and constraints. This group is made up of people who are not part of the ALICIA consortium, but who committed to contribute to ALICIA through their relevant expertise as Helicopter & Aircraft operators, Crew-members, members of Airworthiness & Operational authorities, Representatives of Air Navigation Service Providers and Meteorology experts. At all stages experts are involved to advice on the best way to go towards marketable and certifiable products and systems.

References

[1] Advanced Terminal Weather Products Demonstration in New York, Proceedings of the 11th Conference Aviation, Range and Aerospace Meteorology, 2004.
[2] Project web site: www.alicia-project.eu.

About the Authors

Linda Napoletano
Deep Blue Srl
Piazza Buenos Aires, 20
Roma – 00198 Italy
linda.napoletano@dblue.it
www.dblue.it

Daniel Dreyer
EADS Innovation Works – Department IW-IC FD
Advanced Industrial Design and Visualisation
D-81663 Munich, Germany
Daniel.Dreyer@eads.net

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-253

DELICAT – Demonstration of Lidar Based Clear Air Turbulence Detection

Hervé BARNY

Abstract. Atmospheric turbulence encounters are the leading cause of injuries to passengers and flight crews in non-fatal accidents. A whole class of turbulences, representing 40% of turbulence accidents and designated as Clear Air Turbulence (CAT), cannot be detected by any existing airborne equipment, even modern weather radars. The objective of the European project "DELICAT" – Demonstration of Llidar-based Air Turbulence – is to test an airborne Lidar developed to detect Clear Air Turbulence (CAT) ahead of an aircraft, thus allowing an anticipated reaction to mitigate the CAT effect.

Keywords. Lidar, turbulence, detection, turbulence hazards

1. Context

Atmospheric turbulence encounters are the leading cause of injuries to passengers and flight crews in non-fatal airline accidents. The number of turbulence accidents has increased by a factor of 5 since 1980 (Fig. 1).

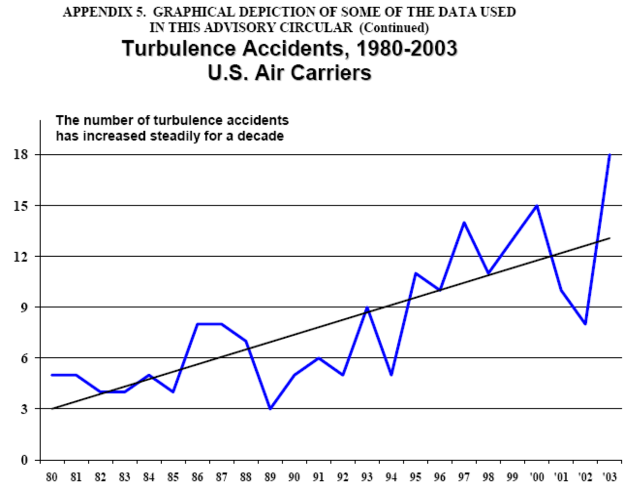


Figure 1. Evolution of turbulence accidents for US air carriers, 1980 to 2003. FAA Advisory Circular AC120-88A, dated 19/01/2006.

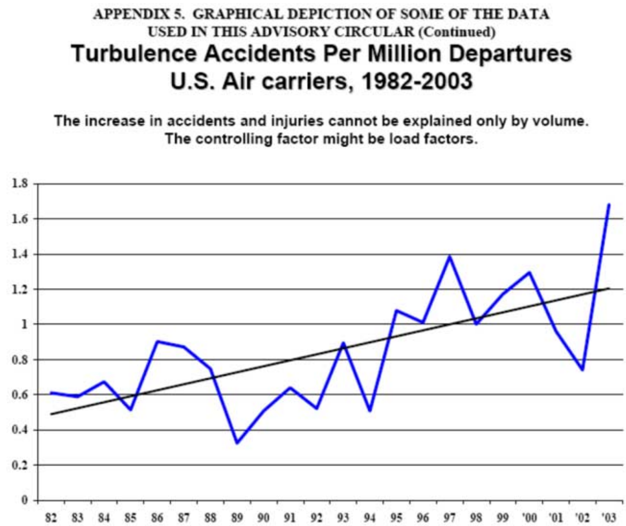


Figure 2. Evolution of turbulence accidents per Mio departure. FAA Advisory Circular AC120-88A, dated 19/01/2006.

Part of this progression is due to the growing traffic, but the rate of accident per million flight departures has also increased, by a factor of 3, since 1980 (Fig. 2). This is probably the result of load factor increasing in this period.

For the aviation transportation industry, the total cost is estimated over 100 MUSD per year. U.S. Federal Aviation Administration statistics show an average of 58 airline passengers being hurt in U.S. turbulence incidents each year. The situation may even worsen in future years, as newly designed aircraft are being designed to allow passengers to circulate freely for entertainment and exercise, especially during long-haul flights.

2. Turbulences Characteristics

The atmospheric phenomena representing hazards for commercial aircraft, due to sudden changes of the aircraft aerodynamic conditions are sometimes conveniently labeled turbulence, wind shear and wake vortex. The CAT is presented in red in (Fig. 3).

CAT can be defined as a changing air velocity pattern, which can give rise to abrupt motion change in the flight path of an aircraft which has been directed through the turbulent patch, if left uncorrected. Turbulence affects the aircraft mainly through variations of vertical wind speed.

While protection against Wake Vortices is ensured through aircraft separation, under the responsibility of Air Traffic Management, and while Wind shear protection equipment (reactive or predictive) is now mandatory for commercial aircraft, turbulence hazard has not yet received a satisfying protection solution.

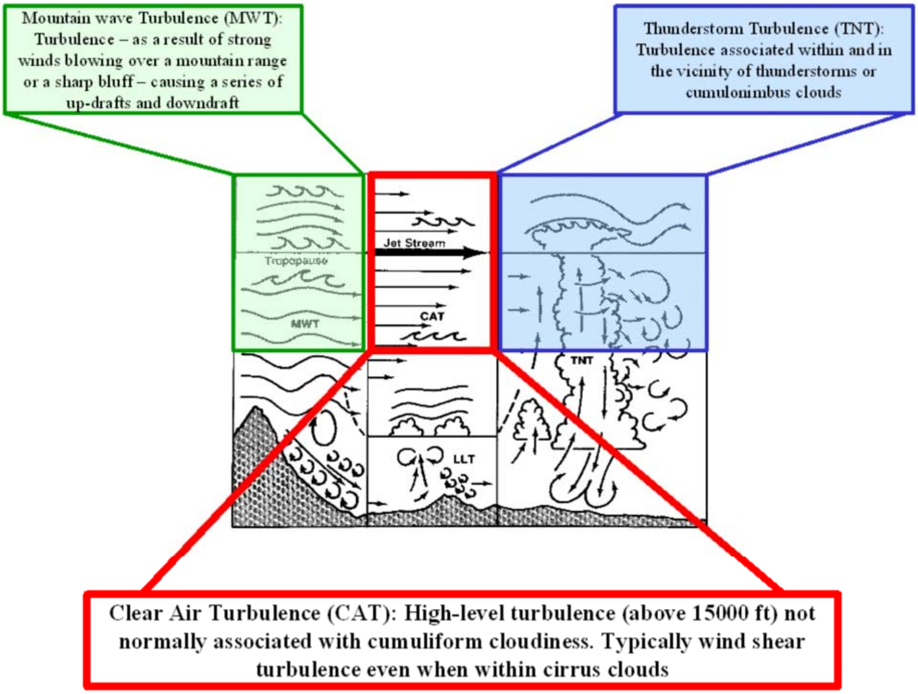


Figure 3. Different types of turbulences.

3. Operational Concepts for the Protection Against Such Turbulence Hazards

- Short-Range (50 m to 300 m) measurement of air speed ahead of the aircraft, and action on the aircraft flight controls to mitigate the effect of turbulence.
- Medium-Range (10 km to 30 km) detection of turbulence, securing of passengers and crewmembers by anticipating seat belts fastening. The DELICAT project addresses this domain of turbulence detection.
- Long-Range, by modifying the Flight Plan for example. This domain is out of the LIDAR range and thus is more related to weather forecasting.

4. General Description of the DELICAT LIDAR System

A LIDAR is an optical remote sensing system, which uses the properties of the backscattered light to obtain information on a distant target or on the atmosphere. The knowledge of the exact position of the portion of atmosphere under analysis with respect to the light emission can be obtained using the time of flight between emission and reception (Fig. 4). Alternatively, the optical system itself can be used to direct and focus the light to a specific place.

LIDAR stands for LIght Detection And Ranging (same as RADAR but using Light instead of Radio). The basic difference between a LIDAR and a Radar system is that optical wavelengths in the ultraviolet, visible, infrared parts of the electromagnetic

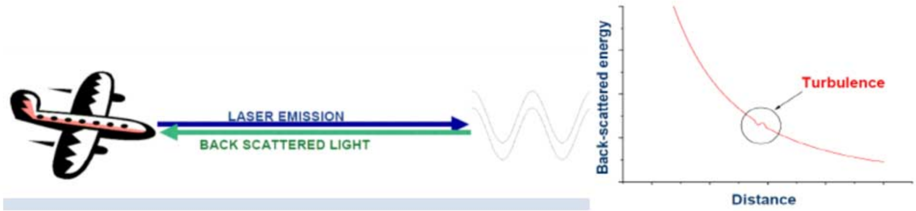


Figure 4. LIDAR backscattered light analysis principle.

spectrum are used, instead of radio frequencies. Since the wavelength used by a LIDAR is much smaller than the one used by the Radar (by a factor of 10^4 to 10^5), the LIDAR can detect much smaller objects than the radar, for example air molecules (N_2 or O_2) or aerosols. Thus the LIDAR is well suited to analyze the clear atmosphere surrounding an aircraft. LIDAR systems use laser beams to take advantage of the high radiation density, coherency and the increased spatial (or angular) resolution available at the shorter optical wavelengths.

5. The DELICAT Remote Airborne LIDAR Will Include 3 Sub-Assemblies

1. Beam Steering to direct the laser beam on the flight path;
2. Receiver (Telescope, Mie/Rayleigh separation, photon counting & analogue PMT);
3. UV Transmitter (Tripled Nd:YAG, 10 W, 100 Hz).

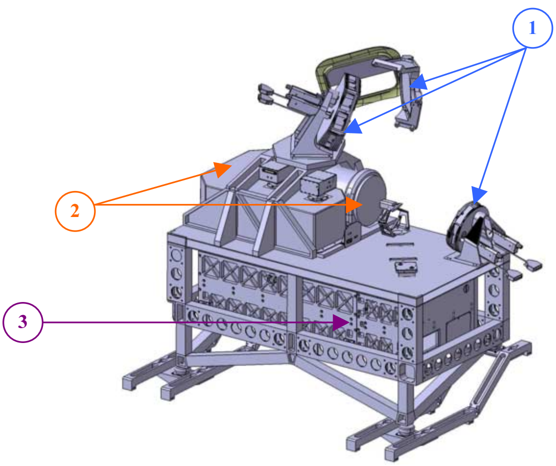


Figure 5. DELICAT LIDAR mock up.

6. Test Aircraft Adaptation for DELICAT

This adaptation requires five measures:

- Fairing to protect the folding mirror to direct the laser beam on the flight path (Fig. 6);
- Nose boom to measure accurately the wind direction;
- Aircraft floor to support the LIDAR;

Figure 6. LIDAR installation on the flight test aircraft.

- Cabin windows to let the laser beam in and out;
- RVSM compliance demonstration.

7. Participation of Meteorological Services and Research Institutes to the "DELICAT" Project

CAT are rare events and not easily predictable. Indeed, partners from meteorological services and research institutes are part of the team, and will support the trials predicting the areas with most chances to encounter Clear Air Turbulences at the date of the flight tests (Fig. 7). It will help choosing the flight region and take the go/no go decisions before each flight.

8. The "DELICAT" Project

The DELICAT Project is a 3 year-and-a-half project, partially funded by the European Commission in the frame of the 7th Framework Program FP5. It also takes advantage of previous FP5 AWIATOR and FP6 FLYSAFE projects.

13 European Partners are involved in the DELICAT project:

- Thales Avionics (France) is coordinating the project
- CNRS (France)
- DLR (Germany)
- Hovemere Ltd. (England)
- Météo France (France)
- NLR (Netherlands)
- ONERA (France)
- INOE (Romania)
- Institute of Atmospheric Physics (IAP, Russia)
- Laser Diagnostic Instruments (LDI, Estonia)
- Warsaw University (ICM, Poland)
- EADS-Innovation Works (Germany)
- Thales Research & Technologies (TRT, France)

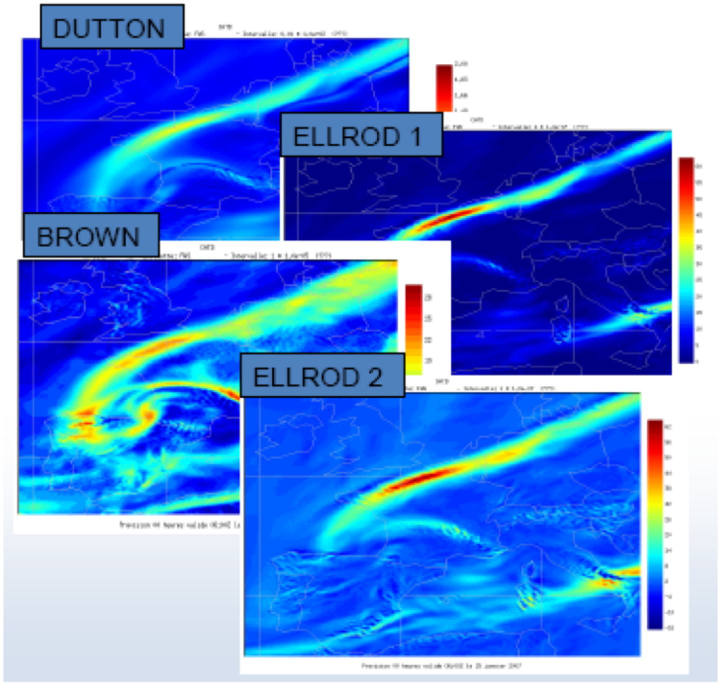


Figure 7. Meteorological support to predict the CAT areas.

9. Main "DELICAT" Objectives

- The main objective is to validate an advanced and new technology for medium-range detection of Clear Air Turbulence;
- The second objective is to analyse the integration of short-range and medium-range functions;
- The third objective is to improve the understanding of Clear Air Turbulence phenomenon, and the CAT forecasting capabilities.

The validation will be based on the comparison of the information provided on the one hand by the remote airborne LIDAR and on the other hand by the aircraft sensors (acceleration, air speed, temperature).

About the Author

Hervé Barny
DELICAT Technical manager
Thales Avionics
25 rue Jules-Vedrines
26027 ValenceTel.: +33 4 75 79 85 11
herve.barny@fr.thalesgroup.com
www.thalesgroup.com

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-259

Improving Turnaround Predictability: TITAN

Developing a New Concept of Operations for the Aircraft Turnaround

Laura SERRANO MARTÍN, Sara M. LUIS NUÑEZ, Ana C. SÁEZ SÁNCHEZ and Sebastian KELLNER

Abstract. Delays in the turnaround are a major cause for low predictability in commercial aviation. The Report "ATM Target Concept" issued by the SESAR Consortium in September 2007 [1] describes the paradigm shift towards trajectory-based operations. With a view to going further in the studies, a R&TD project was initiated by the European Commission within FP7: "TITAN", acronym standing for Turnaround Integration into Trajectory and Network.[1] This project is proposing a concept of operations which integrates the turnaround of aircraft (the turnaround of aircraft comprises the sequence of ground operations required to service of aircraft from the in-block to off-block time) into trajectory and network based on Collaborative Decision Making (CDM) and System Wide Information Management (SWIM) principles. A major point of this concept is the definition of ten milestones in addition to the Airport Collaborative Decision Making milestones. The TITAN concept will be validated by innovative software and further, a CDM tool for airlines will be developed in order to clearly demonstrate its feasibility.

Keywords. Aircraft turnaround, trajectory, bottleneck, buffer time, airport, advanced collaborative decision making

1. Introduction

In 2009, turnaround delays constituted around 70% of primary delays [2]. As turnaround delays were beyond the scope of this report (the focus being on ATM performance), they had not been analyzed and the report just stated that local turnaround delays were caused by airlines (tight scheduling, technical, boarding, etc.), airports (equipment, security, etc.) or other parties such as ground handlers.

This paper directly addresses the airport operations focusing on the turnaround process and the associated delays. It describes a new advanced operational concept for this process fully compatible and complementary with the SESAR ConOps and fully addresses those elements which are not considered ATM-primary elements, such as ground handling processes.

Ground handling is one of the main processes that determine the on-time performance of the Flight Trajectory. It is not only the beginning and the end of the trajectory; it is also the connecting processes between two consecutive flights. The efficiency of this turnaround process determines if delays increase or can be recovered. The

ground process is involved in all phases of the trajectory, from business development through resource planning and allocation to the daily execution of operations.

Turnaround Integration into Trajectory And Network (TITAN) identifies the different processes which interact with the ground sector and how a change of these parameters will have an impact on it [3]. This is done by means of enlarging the Collaborative Decision Making (CDM) scope defining new milestones related to the handling processes during the turnaround phase, paying special interest to the hand-off processes and to the influence of external events like the landside processes.

2. The Turnaround Process

The turnaround of an aircraft comprises the sequence of ground operations and the set of services required to service the aircraft from the on block time to the off block time. Many different actors are involved in the process making it a complex operation with a large potential for inefficiencies.

A series of procedures and specifications have been approved by IATA Airport Services Committee (ASC) and industry standards. These standards have been developed by specialist groups under the direction and approval of the Airport Services Committee as the most practical and economical standards which airlines, ground handling companies and airports are recommended to follow. These groups are open to all IATA Members, IATA Ground Handling Council (IGHC) Members and IATA Strategic Partners [4].

Apart from these, some aircraft manufacturers as Airbus or Boeing [5] develop their own documents for each airplane where a standardized format of airplane characteristics data as the terminal servicing are explained, as certain services must be performed on the aircraft usually within a given time to meet flight schedules.

2.1. Turnaround Service Sequence Diagram

The Turnaround Service Sequence Diagram (TSSD) provides a figure of the current turnaround process. It is the result of analyses of turnarounds focused on the situation at European airports. The TSSD depicts the sequence of the process, names the involved actors and describes the flow of information. In short, it shows who does what, when, and with what information. Collating all this information into the TSSD allows identifying today's inefficiencies and structuring the development of solutions. A graphical representation of a process has to go in line with a reduction of complexity while preserving the cause-and-effect chains. The following paragraph therefore lists the assumptions underlying the TSSD and outlines important findings:

- Only the case where the aircraft stays at the same stand during the turnaround and prepares for a departure is considered; i.e. differences in the process of a flight that moves off stand or does not prepare for departure (e.g. going into maintenance) is not considered;
- Only commercial flights are considered. Therefore other scenarios, such as smaller aircraft that use their own air stairs, are not developed;
- Decision of whether to use bridge or stairs is based on the stand;
- Refueling can be done via truck even if hydrant is available (fuelling company makes this decision);

- No real time communication about remaining fuel on aircraft;
- It is assumed that fuel truck always contains at least the required quantity of fuel;
- Refueling can be done with passengers on board if fire department has been notified;
- In some cases, cleaning can be performed by cabin crew;
- In some cases, some tasks may be omitted (e.g. no catering on low cost carriers);
- Bridge or stairs and all baggage handling equipment remain in position for the duration of the turnaround process;
- Both cabin crew and passenger agent assist with the boarding process;
- Headcount and passengers on board reported from passenger agent match;
- No passenger is missed;
- Check-in gives passenger information to load control for the load sheet. With this information load sheet is done and it is given to flight dispatcher to deliver it to the cockpit crew;
- There are no changes in the load sheet;
- Provision of air starter has not been included within the TSSD.

The TSSD is composed of three diagrams. The highest level is marked by the TSSD Overview Diagram (Fig. 1), which provides an overview of the whole turnaround process. It illustrates those activities (dark orange), milestones (green rhombi) and actions (boxes with numbers as headlines) which do not require a separate diagram.

The next more detailed level is the TSSD Activity Diagram. It illustrates the actions in the activity, messages passed, completed actions and any completed milestones. At the same time it highlights parallel activities and clearly identifies the flows of activities for each actors to complete the action. An example based on the Unload Baggage/Cargo/Mail process (Fig. 2).

The most detailed level is the TSSD Action Diagram. It further decomposes an activity with multiple subtasks and parallel activities. This helps in identifying missing information flows where actors should share information. Figure 3 continues the description of the example of Unloading Baggage.

Summarizing, the turnaround involves activities by different actors which are dependent of each other or may run in parallel. The detailed analyses revealed further dependencies on the action level. Obviously dependent actions require sufficient coordination between the actors in charge of performing the actions. High resolution images of the complete TSSD are available in [6].

2.2. Actors

Different organizations carry out the turnaround activities through individual actors who have different roles and responsibilities in the turnaround process.

The main actors involved in the turnaround process are aircraft operator, ground handler, Air Navigation Service Provider (ANSP) and airport operator. They have been defined taking into account European legislation on access to the ground handling market [7] and the activities carried out within the process.

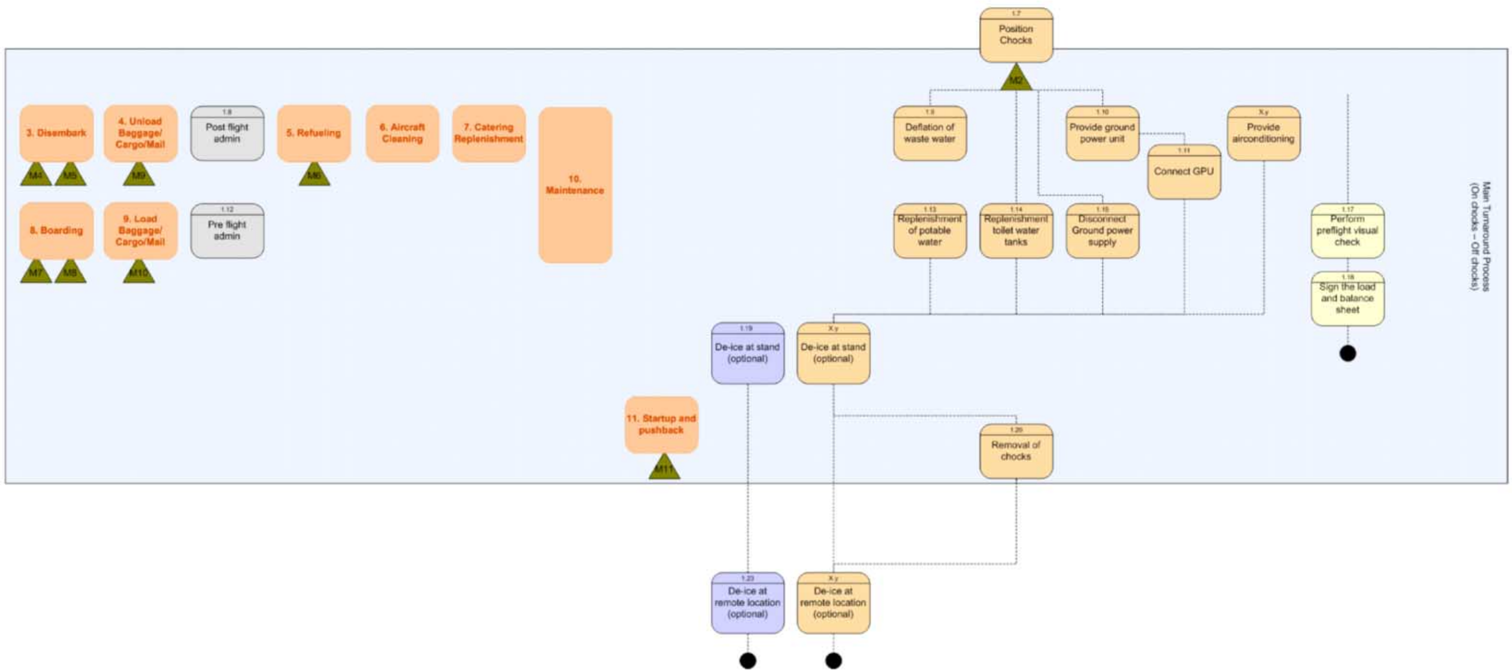


Figure 1. TSSD Overview Diagram.

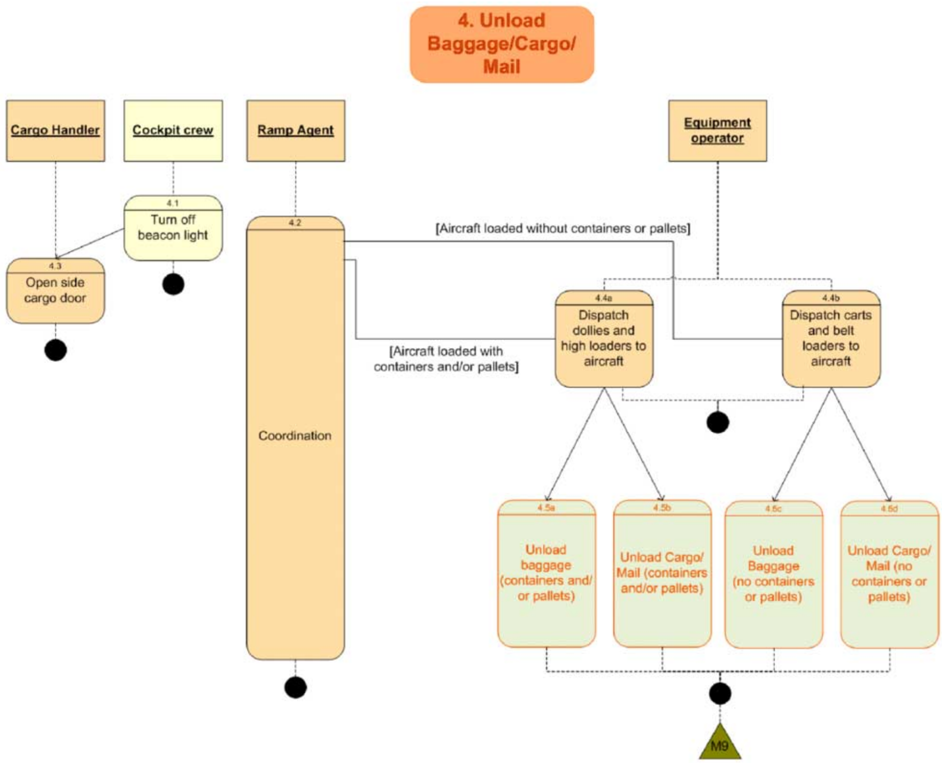


Figure 2. TSSD Activity Diagram.

In addition, they have been classified according to their specific roles during the turnaround process. It has been difficult to unify these because depending on the country, the same role can be carried out by different actors. In these cases they have been pointed out. The following definitions apply:

- Actor: an actor is any entity that interacts with the Air Traffic Management (ATM) Network. It might be a human user, an organization or a computer system. Actors are consumers or providers of services.
- Role: a role is an office or a function (i.e. a set of related activities or tasks) assumed by an actor. More than one role may be assigned to an actor.

Table 1 below exemplifies the different notions of actor and role by describing the airport operator. The organization unit employs individuals who execute different roles.

2.3. Bottlenecks and Buffer Times

2.3.1. Bottlenecks

Airports are becoming the bottleneck of the air transport network since their resources cannot currently keep up with the air traffic demand due to its rapid growing. Airport delays are mainly addressed to the inefficiency of daily airport operations and the non-

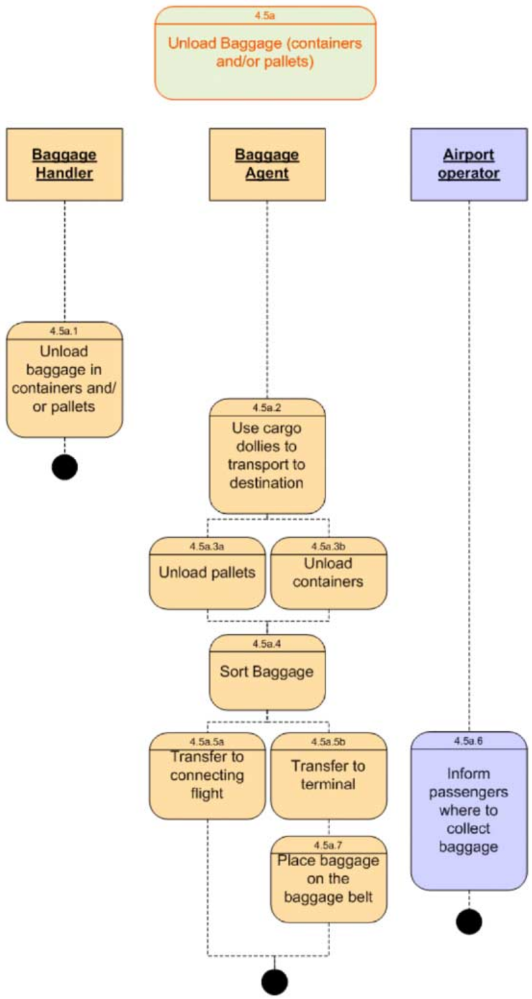


Figure 3. TSSD Action Diagram.

availability of reliable information. All airport partners lack current global situational awareness due to inadequate information sharing or fragmented information flows.

The turnaround for various aircraft in an airport is an optimized process by each stakeholder involved. They optimize their own resources to perform their tasks in the agreed time. However, they do not share a common view of aircraft evolution and use different planning data, and no single partner has a complete image of turnaround processes and resources. There is no integrated planning of the turnaround process itself, and therefore the precise predictability of the flight's estimated off block time is generally poor.

During the execution phase, delays become when a deviation from the original schedule arises (not only delays, but also being early is not always desirable as it could cause blockage), mainly due to the unavailability of means which may lead to a chain

Table 1. Actors and Roles – Airport Operator

Individual	Main Role(s)
Airport operator	• Update resources' availability • Updating data related to passenger (information from airport devices, e.g. cameras located to monitor passengers) • Inform passenger where to collect luggage • Stand allocation • Gate allocation
Marshallers and follow-me drivers	Guide the aircraft to the stand allocated
De-icing staff	De-ice
Reduced Mobility assistance	Assist to disabled passenger Locate ambulift
Automatic system/Load flow on terminal personnel	Baggage security process
Met office	Provide weather information reports and forecasting
Security personnel	Passenger security control

reaction of delays. Stakeholders take decisions separately and based on different information instead of managing a single, unique set of information.

In these circumstances the lack of information shared, or the provision of this information too late, does not let the involved actors to be adapted to the new scenario as soon as possible and leads to the late arrival of ground handling agents and equipment at the gate.

The lack of continuous monitoring and update of the information during the execution phase is mainly due to two facts: insufficient or unreliable information among partners (relevant information exists somewhere around the airport in various systems, but is not readily available to all partners) and restricted information sharing (some partners are unwilling to share information because they consider some data "commercially sensitive" or the sharing of the information demands extra work from them). Besides, the use of different codification, tools and applications by each stakeholder to deliver their specific services and the use different terms do not facilitate this task.

Passengers are also considered as an important source of turnaround delays. Their behavior cannot be predicted nor inside neither outside the aircraft, and their late arrival to the boarding gate could cause delays due to the short reactionary time.

The increasingly trend of demand of security processes may also be a cause of bottlenecks during turnaround processes. This issue is strictly dependant on security regulations. Airports have difficulties in complying with these regulations since it has a direct negative influence on airport operations as it produces additional delays. It is something unfavorable for airports according to their goals of reducing aircraft turnaround times.

Overall poor information sharing and poor management prevents efficient coordination between all stakeholders resulting in a less effective use of available assets and therefore increasing the hidden costs to the airspace users in the form of operational inefficiencies, such as a non-optimized turnaround process. It may cause inefficiencies in predictability, efficiency and cost effectiveness KPAs.

2.3.2. Buffer Times

All turnaround processes are scheduled against the Scheduled Time of Arrival (STA) and, by assuming a dedicated taxi-in time, against the in-block times at the assigned stand, (either remote or at the terminal building) according to the airport stand allocation scheme. All disruptions occurring between two connecting flights unavoidably cause some damage in the ground operations since personnel resources are tight and tools are partly specific for aircraft types. Therefore, the aircraft turnaround performance relies on a robust stand and aircraft allocation scheme over the day.

In order to achieve the performance targets typically introduces buffer time calibrated by expert knowledge during the operation onto technical minimum gate times. It seems not to follow rigid rules or to apply a systematic concept. Furthermore, the technical minimum gate time itself is not a constant value per type of aircraft, as it is influenced by other external aspects such as the type of flight, if the flight has or not any cargo, the number of passengers, internal procedures, etc.

The correct calculation of buffer time can minimize system costs by balancing trade-offs between schedule punctuality and aircraft utilization. The optimal schedule time for a turnaround aircraft depends on the arrival pattern of inbound aircraft as well as the scheduling strategy of an airline. When the expected delay cost is relatively lower than the operating cost of an airline, the airline might choose to minimize the turnaround time to reduce operating costs and to increase fleet productivity.

To fully understand the concept behind buffer time, here is an example of its use: Given that the cleaning of the aircraft (task) will take y minutes while the whole cleaning process (plan) is scheduled to take x minutes. Then

$$t = x - y \tag{1}$$

simply defines the time buffer t as difference between plan and task.

The buffer time allows a slight delay in the start of the cleaning process or in the course of it. The maximum delay that the system can tolerate without compromising the termination of the subsequent processes in due time is t. Knowing that the cleaning process needs y time to be finished, if the delay at start exceeds t, the next processes (which is dependent on the previous one) will probably suffer a slip (unless it also has a time buffer that can be consumed in favor of the cleaning process).

Unless arrival delay is longer than the scheduled buffer time in turnaround schedules, it has been observed that the arrival lateness does not necessarily result in departure delays. The schedule buffer time could be used to absorb arrival delays, unexpected departure delays due to ground handling disruptions and to accommodate inevitable time gaps in flight schedules.

According to queuing theory, the buffer depends on the delay magnitude of an individual turnaround but a late aircraft may need less buffer time than is expected due to an increased pressure to meet the schedule.

Finally, buffer times could be introduced for the turnaround as a whole or, more specifically, in between the processes along it. The question of the best time buffer to cope with both aspects is crucial.

3. Stakeholders' Needs

Anyone that has any input to, or is in any way affected by the implementation of the proposed concept is a stakeholder. The co-operation and advice of stakeholders is vital to ensure that a good operational concept is developed and that it responds to their daily needs and concerns. In order to satisfy these needs, a stakeholder analysis identifying all interested parties and, a discussion of the level of involvement they wish to have regarding this analysis (stakeholder expectations), is required.

3.1. Methodology

To identify the stakeholders' expectations several information sources are used. The main source to collect the majority of stakeholders' requirements is through interviews with a pre-defined questionnaire and phone calls. The interviewees could fill in the questionnaire and they sent them back via e-mail. To allow the stakeholders to freely express their opinion, the questionnaire, contained guided and open questions regarding the likely impact of the TITAN concept on the efficiency of the turnaround procedure.
Some other sources are used to get more information regarding their needs. A workshop was held, where external participants and consortium members discussed the issues related to the turnaround process [8]. Representatives from all actors involved in the turnaround process took part during the workshop in a brainstorming session in which they helped to define an improved turnaround process, taking into account their necessities. Also, an in-depth analysis of available documentation was performed to provide an additional set of issues, gaps and necessities to be solved.

After running the interviews, a methodology for analyzing the requirements is followed. The received data is systemized and analyzed. The analysis also highlighted if the requirements are within the scope of TITAN or not, but in any case, the collected stakeholder requirements may not be enough for the scope and some important requirements could be missed.

In order to complete the list of requirements, it is also needed to start from the TITAN scope and identify the main goals that need to be reached. In this way a bottom-up approach from the analysis of the collected data and a top-down approach from the TITAN scope are converged in a unique list of requirements.

The analysis, bottom-up methodology, allowed organizing the information, to elicit the requirements, to complete the requirement by a deep understanding of the process and also to show the relation between different requirements.

The TITAN scope, top-down approach, facilitates to create a final uses list. Also it is helpful to compare similar final uses according to its meaning. The general goals will be more specific and each requirement is attached to their related goal.

Figure 4 illustrates the combination of approaches to develop the TITAN requirements.

3.2. Short Summary of Requirements

The stakeholders were interviewed through questionnaires about the turnaround process [9]. They were asked about the activities and resources they would like to monitor and the actions they would be ready to collaborate with. They also expressed their

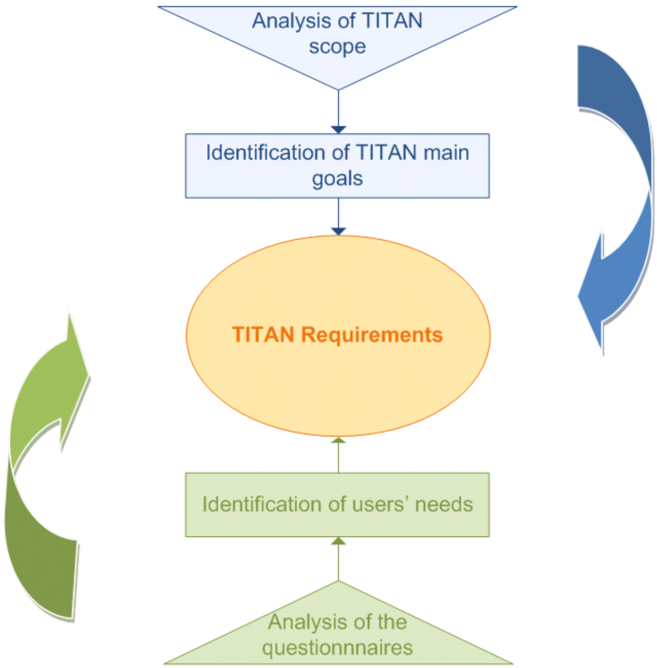


Figure 4. Approaches to TITAN requirements.

ideas regarding the changes that would improve efficiency of the turnaround process and they have the following conception:

A better information exchange is required, and it could be reached by the application of CDM mentality, or with collaboration between the different actors involved sharing the information they have. Some of them have their information in their own database but an integrated central database would be a good way to get better results. Also other requirement from stakeholders is an increase of communication between ANSP and Ground Handling Agent during arrival and departure. They need more up-to-date information about gate allocation: it was mentioned that the aircraft type, the time needed for fuelling and other actions as well as the stand limitations should match as well.

To improve the efficiency of the turnaround is necessary to share supplementary information. Passenger movement like passenger check-in or passenger trough security control or passport control is really valuable for Handling Agents and Aircraft Operators. Regarding disabled passengers and UMs, more punctual information would help the work of the Ground Handlers and this would also provide valuable data for the Aircraft Operators. It was proposed to investigate the possibility to eliminate the rules that forbid baggage to travel alone, if and only if the passenger and the baggage come from a secure origin (and therefore have been already inspected) as the delayed passengers cause a lot of problems within the turnaround.

In order to facilitate the implementation of all these requirements, stakeholders suggested developing information systems that could unify the mandatory shared information. An automated decision making in some of the services (e.g. how many check-in desks should be opened) would help the work of the airlines and handling

agencies. To standardize the different systems, common interfaces for each stakeholder and updating policies to integrate check-in interfaces would help the work of the check-in agents and passengers checking-in at self check-in kiosks. The actors involved on the turnaround process could have easier access to the information (hand held) if the territory of the airport could be covered with Wi-Fi.

Apart from these needs, they suggest to implement general policies focused on the overall performance of the turnaround, the use of GPS systems to monitor resources, such as passenger buses or containers (ULDs) and to improve situational awareness.

3.3. Information Tree

Information trees are predictive models, used to graphically organize information about possible options, consequences and end value. If the requirements and goals have been elaborated and structured, an information tree can be prepared. Due to the size of the TITAN information tree, the Fig. 5 below only shows an example of how it looks like.

The information tree below shows how the requirements of the stakeholders can be matched to the TITAN goals and scope. In the centre of the information tree the scope of TITAN is described, while on the side branches the goals can be found.

These goals are identified in such a way to ensure that the TITAN targets are fulfilled.

The goals derived from the scope of the project are:

- Increase predictability;
- Improve efficiency;
- Reduce operational costs (cost-effectiveness);
- Enhance situational awareness.

Following a top-down approach, to be able to better identify detailed requirements linked to predictability and efficiency goals, requirements have been divided into Action and Estimation type requirements. One information tree has been associated to each type. Users information requests can be related to “know if something IS GOING TO happen in order to DO something” (action type requirements linked to “Efficiency” goal) or to “estimate the PROBABILITY OF something to happen in order to be ready” (estimation type requirements linked to “Predictability” goal).

4. The TITAN Concept of Operations

The Concept of Operations describes how the turnaround process will be performed from different perspectives: it identifies the functions and processes, and their corresponding interactions and information flows; concerned actors, their roles and responsibilities.

The functional scope of this concept is build upon what has been implemented in Advanced-Collaborative Decision Making (A-CDM) and it is delimited by the planned developments in SESAR IP2. Within those bounds, the ConOps proposes a CDM development that fully exploits either existing capabilities or others that can be implemented in the short term, one resulting in an expanded version of information sharing practiced in A-CDM.

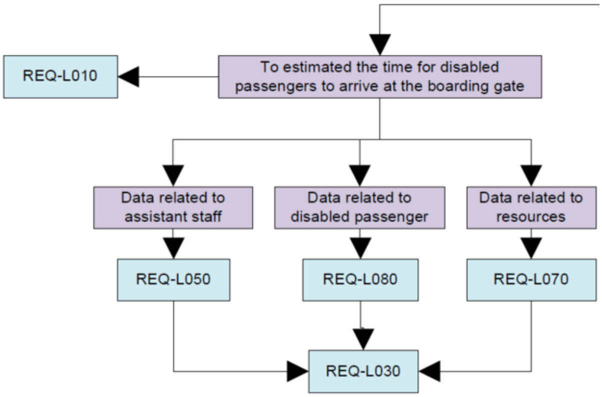


Figure 5. Information tree.

4.1. Needs for a New Concept

Air traffic is growing so rapidly that the airport resources cannot keep up with the demand and airports are becoming the bottleneck of the air transport network. However, airports are key nodes of the aviation network and their throughput is one of the main processes that determine the on-time performance of the RBT (Reference Business Trajectory). Particularly, the efficiency of turnaround processes determines if delays do increase or if they can be recovered.

The new advanced operational concept for the turnaround process is expected to unify and optimize the different aspects related to this process through the increase of predictability and efficiency, reduction of operational costs and enhance the situational awareness of the stakeholders involved. The concept takes into account the relevant landside processes and is based on the principles of Collaborative Decision Making and System Wide Information Management.

The aircraft turnaround process comprises the sequence of ground operations required to service the aircraft from the in-block to the off-block time. The scope of TITAN shall encompass the processes included in the turnaround as well as those external services, which have a direct influence on it. The concept identifies and describes the standard turnaround functions and processes, as well as their corresponding interactions and information flows; concerned actors, their roles and responsibilities. Therefore an extended handling view will be ensured by including processes hitherto not, or not fully, considered in the Collaborative Decision Making view.

4.2. Processes Within the Turnaround

This section categorizes the processes included in the turnaround depending on their scope and lists those external services, which have a direct influence on it. In the scope of this paper, "process" is defined as a sequence of interdependent and linked procedures which, at every stage, consume one or more resources (employee time, energy, machines, money) to convert inputs (data, material, parts, etc.) into outputs. These outputs then should serve as inputs for the next stage until a previously established goal or end result is reached. We consider the turnaround as a process composed of several sub-processes. Its final objective is to prepare the aircraft and achieve the AOBT on

time following the agreed 4D trajectory. Each process produces or contributes to a specific service, most of them used as inputs for other sub-processes. Understanding a service as something that is needed for the process to proceed, the subsequent delivery of services contributes forward the overall aircraft turnaround process completion.

The grouping of processes bundles those with close relations. We consider the following five categories as helpful in understanding the proposed ConOps:

- Airside processes;
- Landside processes;
- Common processes;
- Off-Airport processes and
- Network processes.

The first two categories differentiate between the movement area of aircrafts (airside) and mainly passenger related processes (landside). Airside processes are:

- Passenger embarking/disembarking (including disabled passengers and unaccompanied minors);
- Loading/unloading of baggage;
- Loading/unloading of cargo/mail;
- Location of air bridge and stairs;
- Refueling;
- Aircraft cleaning;
- Catering replenishment;
- Maintenance;
- Start-up and push-back;
- De-icing at stand;
- Stand allocation.

The landside processes deliver the passenger to the boarding gate. Landside processes are:

- Check-in;
- Assistance to disabled passengers and unaccompanied minors;
- Passenger security control;
- Passenger passport control (if applicable);
- Passenger boarding/de-boarding;
- Baggage security process;
- (Boarding) gate allocation.

Common processes stretch across the boundary between airside and landside and provide information on the whereabouts of passengers. The process passenger tracking consists of the scanning of the boarding pass at process stations and generating an immediate warning to the passenger if flight departure is within a set time period. This method has not to be understood as permanent passenger monitoring. A similar approach applies for tracking of baggage and cargo/mail by scanning of tags at process stations.

Off-airport processes are only incidentally connected with the turnaround but can have a major influence on operations. One example is the access to the airport facilities.

It mainly includes ways of transportation (e.g. train, motorways, taxi service, underground…), its availability and frequency.

4.3. Services in Support of Process

In order to be executed, the processes identified require various services. Conceptually the services in turn, support end-user applications which are the operational interface to the outside world (for humans) or to external environments without human intervention. Services in the TITAN concept of operation context include both operational and supporting services but exclude technical/IT services. All services use the shared information space of the TITAN net-centric environment (TITAN Information Sharing) and as such are interrelated and do not work in isolation.

The run of the processes generate information flows between the actors/entities of the turnaround process. Each process requires special information for the proper execution of the procedure and generates information which can feed other processes. This information is provided by different services. Conceptually, three main flows are distinguished:

- Passenger flow;
- Baggage flow;
- Cargo/mail flow.

These flows meet at the aircraft, while they are managed and connected by the end-user applications. In the following paragraph we explain the conception of the Passenger Flow Information Service (PFIS).

The passenger flow process is subject to several possible disturbances at different points of the flow. The effects of a disturbance depend to a large extent on the organization of the process which determines where the source of the disturbance is located. Tightened security or a scanner failure will impact the process differently where the passenger screening is centralized or is boarding gate based.

The information generated by PFIS is published into the shared information space to be made use of by different end-user applications. Following this rationale, the purpose of this service is to provide real-time information on the passenger flow on and beyond the airport as an enabler for warnings (when comparing the actual and the planned information) and intelligent applications that can react to disturbances in the passenger flow with a view to mitigating their effect.

PFIS requires the implementation of facilities that can monitor the passenger flow at different, required points, correlating the movement data and trends to generate the appropriate conclusions. It is important to remember that passenger tracking may involve issues related to the need for protecting personal data. Such issues are out of scope of this paper but will have to be addressed and properly resolved.

The remaining two flows are covered by similar services providing detailed information about the location of baggage, cargo and mail. As explained above, these three flows meet at the aircraft, which is the focal point of turnaround. Therefore an Aircraft Status Report Service (ASRS) is needed, collecting and forwarding the status and position of the aircraft. The environment of the turnaround is covered by the Airport Information Report Service (AIRS) providing information about the availability and location of the airport facilities (e.g. boarding gates). It can serve as the primary trigger for

users of the airport to consider eventual modifications to their trajectories taking into account present and future considerations, such as meteorological conditions.

4.4. Applications of Services

The TITAN Information Sharing (TIS) will use the existing infrastructure at airports and will be improved by combining data from different sources. However, adaptations of existing information systems might be required in order to include or correlate data that is not currently available.

TIS is a virtual central data repository, where all scheduled, estimated, actual and target (when applicable) times are transferred to and distributed by the services. End-user applications will be specifically designed to share this information with stakeholders' systems.

Defined rules determine responsibility and quality of information at each stage. This provides all partners with a common overview of the real-time turnaround, as well as the expected progress of the planned operations. The result will be a common situational awareness of the involved actors resulting in an efficient use of the available resources and in more predictable operations.

4.5. Milestone Approach

TITAN milestones are defined in order to support the tracking of the process progress, the awareness of deviations during the planning or progress of the aircraft trajectory and their impact on later parts of the trajectory at an early stage.

TITAN Milestones Approach is expected to link air and landside processes in order to improve information flows and to predict forthcoming events. Milestones are defined during the planning as specific time objectives which have to be reached in a collaborative way and, in the case a deviation is anticipated, mitigation measures have to be agreed among involved partners. The outputs of each milestone are, in case of deviation from planning, alert messages to turnaround partners which let actors react against changes.

Milestone monitoring is a turnaround cooperative mechanism which improves visibility of the process progress for turnaround actors and results in better estimated times of subsequent events across the in-off (block) milestones. The goal is to allow re-planning turnaround activities among involved partners. To reach this objective it is needed to be able to anticipate changes and disseminate the information among all involved partners as soon as possible.

TITAN is aligned with and complements A-CDM through a better management of the turnaround. TITAN will use the procedures and rules established for A-CDM supplemented by those specifically developed for the turnaround. Besides A-CDM milestones as listed in [10], a set of specific turnaround milestones are defined to support the monitoring of the turnaround process progress as shown in Table 2.

5. Alignment with SESAR

The SESAR (Single European Sky ATM Research) programme is one of the most ambitious research and development projects launched by the European Community. The

Table 2. TITAN milestones

TITAN Milestone	Rationale
M17. Close check in	Boarding can start. Passengers and baggage list closed.
M18. Last passenger crossing security control	Passengers monitoring. Means to know whether a passenger arrives to boarding gate on time or not.
M19. Last passenger crossing passport control	Passengers monitoring. Means to check whether a passenger has been rejected at passport control.
M20. End of deboarding	Ground handling activities on passenger cabin can start.
M21. Last baggage delivery to hold baggage bay	Baggage monitoring.
M22. End of baggage unloading	Baggage loading can start.
M23. Close cargo doors	Baggage monitoring.
M24. Start of fuelling	Inform firemen if needed. Specific processes have to be ready to start fuelling.
M25. Remove push back	Stand and gate available. Aircraft can move by itself.
M26. End of de-icing	Time for takeoff is limited.

programme is the technological and operational dimension of the Single European Sky (SES) initiative to meet future capacity and air safety needs.

This TITAN concept is intended to deliver additional benefits to those available from A-CDM (to be implemented in SESAR IP1) during the early stages of the SESAR IP2.

SESAR "Airport Operations" and this concept have several common areas of interest and are perceived as complementary initiatives. For that reason a coordination mechanism has been established to avoid potential overlapping: SESAR will not fully cover non-ATM processes (e.g. landside), while TITAN directly addresses such processes. Considering a high level description of the SESAR AirPort Operations Centre (APOC),[2] the puzzle is closer to completion (at an early stage) when this concept is in place as it ensures that monitoring of landside processes (passengers, baggage, cargo and mail) is in place (Fig. 6).

Furthermore, the concept elements addressed by TITAN can be seen as enablers for and facilitators of the achievement of the SESAR CDM objectives. This is achieved by:

- Building on a net-centric design principle;
- Using trajectory based operations as the means to integrate airports into the ATM network;
- Defining services that act on the processes that are the subject of analysis following a Service Oriented Approach (SOA);
- Making use of CDM and SWIM principles.

This approach is aligned to that used in SESAR, but limited to turnaround operations.

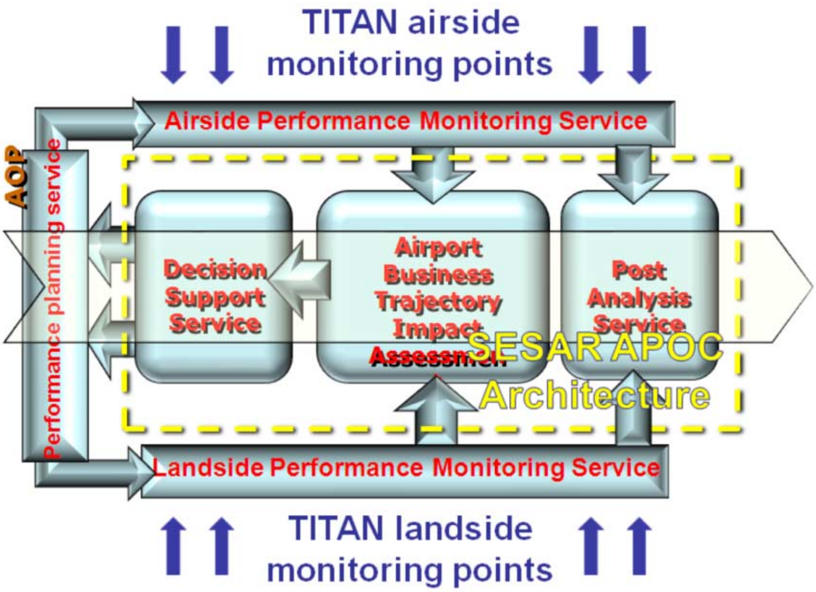


Figure 6. APOC architecture and TITAN.

TITAN is also aware of the existence of other ATM initiatives, such as NextGen in the USA. Both SESAR and NextGen represent key global initiatives on the air traffic system, and their compatibility is a must, carried out by agreements between UE and FAA and through an open system design and dedicated international activities. FAA not only collaborates with Europe, but also with other authorities such as Canadian, Mexican, Chinese, Japanese, Brazilian and Indian authorities in order to carry out similar initiatives.

6. Next Steps

The turnaround process is embedded into the airport operations with a major influence onto the air transport performance. The next step we focus will consist in validating the TITAN concept to assess its effect on the predictability and efficiency of airlines operations as well as its operational feasibility. This validation will be performed by gaming sessions and by innovative software that will be developed within TITAN project and which will model the turnaround processes of the different aircraft at an airport. The results from these validation activities will be analyzed and will provide feedback to further improve and refine the operational concept, with particular attention to identifying the warnings raised when there is an unacceptable discrepancy between any planned and actual event.

Further, a demonstrator for a CDM tool will also be developed to show the feasibility of the model within TITAN project. The tool will allow for the negotiation and finalization of TITAN milestones as well as the publication of progress information related to them. It is expected that the overall solution will be integrated in future CDM processes at an airport, taking into account the technological communication among the stakeholders.

Endnotes

---

[1] The work described herein has been cosponsored by the European Commission as part of FP7 and the TITAN consortium.

[2] The APOC that will be developed in SESAR is a physical or virtual room where airport actors and stakeholders collaborate to develop, coordinate, maintain and communicate real-time joint plans in their individual area of responsibility.

References

[1] SESAR Consortium, "Deliverable 3: The ATM Target Concept", issued by the SESAR Consortium on September 2007.
[2] Performance Review Commission, "Performance Review Report 2009", Eurocontrol, May 2010.
[3] TITAN Project homepage: http://www.titan-project.eu/.
[4] IATA, "Airport Handling Manual", 27th Edition, 2007.
[5] Boeing Commercial Airplanes, "737 Airplane Characteristics for Airport Planning", Boeing Commercial Airplanes, Seattle, WA, 2010.
[6] TITAN Consortium, "Deliverable 1.4: TITAN Operational Concept", issued by the TITAN Consortium on October 2010.
[7] Council of the European Union, "Access to the groundhandling market at Community airports", 96/67/EC, of 15th October 1996.
[8] TITAN Consortium, "Deliverable 7.7: Report on Stakeholder's needs Workshop", issued by the TITAN Consortium on June 2010.
[9] TITAN Consortium, "Deliverable 1.2: High Level User Requirements", issued by the TITAN Consortium on October 2010.
[10] Eurocontrol, "Airport CDM – The Manual", Eurocontrol July 2010, p. 57. Available online at: http://www.euro-cdm.org.

About the Authors

Laura Serrano Martín
Head of Department of ANS European Projects
INECO
Avda. Del Partenon, 4-6, 4th floor
28042 Madrid, Spain
laura.serrano@ineco.es
www.ineco.es
Sara M. Luis Nuñez
Department of ANS European Projects
Same address as above
sara.luis@ineco.es

Ana C. Sáez Sánchez
Department of ANS European Projects
Same address as above
ana.saez@ineco.es

Sebastian Kellner – Department of Airport and Air Transportation Research –
RWTH Aachen University, Aachen, Germany
kellner@airport.rwth-aachen.de

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-277

SWIM-SUIT: The Baseline for the System Wide Information Management

Giuliano D'AURIA, Dario DI CRESCENZO and Antonio STRANO

Abstract. The management of different types of ATM (Air Traffic Management) information has until now evolved independently as each stakeholder gathers its own data independently and asynchronously. As a result of this bottom-up approach, today's ATM information systems are insufficiently integrated, resulting in organisational and institutional barriers which prevent the timely use of relevant information and the optimization of the entire system. It is in response to this fundamental challenge that the vision of SWIM (System Wide Information Management) has been identified as a fundamental enabler for the ATM system of the future. The need for SWIM is widely recognized and lies at the very heart of the future ATM defined within both the SESAR and NEXT Gen initiatives. The main objective of SWIM is to enable a seamless information sharing between the air transport stakeholders as, for example, airports, airlines, military air defence and air traffic control centres, Air Navigation Service Providers (ANSP) etc. SWIM opens up a collaborative environment within a highly distributed system of systems including the most diverse ATM players, each with their own background and needs. It constitutes the future software infrastructure which will interconnect the multiplicity of stakeholder and systems which take part in the ATM domain.

Keywords. System wide information management, ATM, SESAR, NEXTGEN

1. What Is SWIM-SUIT?

The recently completed SWIM-SUIT Project involved a large international consortium led by SELEX Sistemi Integrati, with the objective of assessing the feasibility of SWIM through the realization of a first prototype connecting stakeholder applications representative of the future SESAR's environment.

The SWIM-SUIT project has given the possibility to the project partners to have hands on experience in realizing a first SWIM prototype. This has provided a unique opportunity to test and experiment solutions and technologies capable of supporting the flexibility and decoupling mentioned above.

The fundamental problem of enabling interoperability between a heterogeneous set of systems and stakeholders has been faced by structuring the analysis on a per "data domain" basis as also suggested by the SESAR approach [1]. The establishment of a common dictionary in terms of data and services is, of course, one of the enablers for systems interoperability. Flight and Surveillance data domains have had the greatest attention during the design and modelling phases; in the first case, the work has adopted as baseline the results of the ICOG2 project [2] which defined a "Flight Object" model further extending the FOIPS [3] model, while in the latter an "ad hoc" dictionary has been developed supporting the current ASTERIX CAT 62 [4] standard for surveillance information.

The determination of the data and service model has involved different stakeholders (e.g. Airport Operation Centers, Airline Operators, Network Information Management, Air Traffic Control Centers, etc.) leading to the extension of the Flight Object structure so as to cover stand to stand information. Of course, also the service model has been correspondingly extended enabling the interaction with stakeholders not considered in the ICOG scope.

1.1. Swim Prototype Design Outline

In order to instantiate and validate the applicability of the SWIM concept, during the course of the SWIM-SUIT project a SWIM prototype, consisting of a fully decentralized architecture, has been developed.

The architectural solution developed by SWIM-SUIT is based on the Swim-Box®, which represents the access point for stakeholder applications to enter the SWIM world.

Swim-Box® acts as gateway towards the SWIM collaborative environment and shields the applications from the details and complexities of the SWIM technical implementation, thus providing independence from SWIM technological choices.

Swim-Box® therefore provides an entry point and interface for the most diverse applications representing the air transport players to plug into SWIM, taking care of the complex communications patterns supporting the large distributed systems. This allows ATM stakeholder applications to focus on their key functions while leaving the management of communication aspects, including security and data distribution, to the Swim-Box®.

The Swim-Box® high level architecture has been structured in basically two layers: a core layer offering a set of common services and components to the upper layer (e.g. security, data distribution, and registry) which was then in charge of offering specific domain services (e.g. subscriptions to flight data, notifications of incoming flight information, subscription to surveillance information etc).

Only Swim-Box® instances are allowed to directly exchange data and invoke services over this network; therefore they act as mediators with respect to the external clients (e.g. Flight Data Processor systems). The ATM Systems participating in the SWIM-SUIT project were not aware of the services and functionalities of the SWIM prototype and used their own technology to exchange and represent information. For this reason, on each site the task of interfacing the “legacy system” to the Swim-Box® instance was assigned to an “Adapter” component. Both for security reasons and for ease of configuration, the different Swim-Box® nodes have been connected together via VPN (Virtual Private Network) connections. The resulting high level structure can be therefore illustrated (Fig. 1).

The end to end interaction among ATM systems in a SWIM Network may therefore be depicted as in (Fig. 2).

Each ATM system exchanges data and provides/consumes services via the mediation of the Swim-Box® component which assures a common dictionary for each of the data domains supported (e.g. meteo, flight data, surveillance, etc.) enforcing the respect of security policies (e.g. restricted access both to data and to services). The Adapter architectural component shown in (Fig. 2) will probably be removed (or incorporated) in the future ATM systems which will be natively able to interact with the SWIM infrastructure.

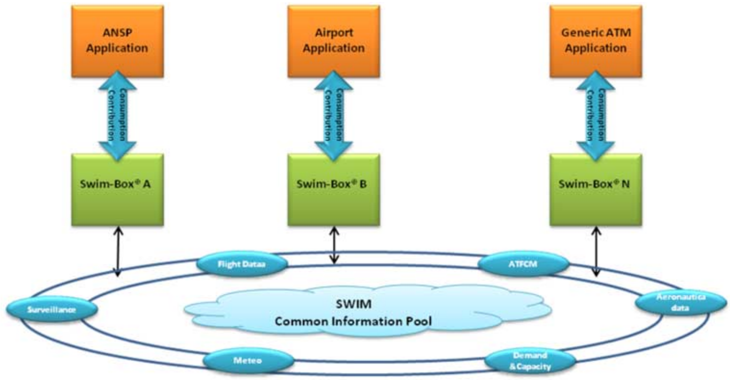


Figure 1. SWIM-SUIT prototype complete instance connections.

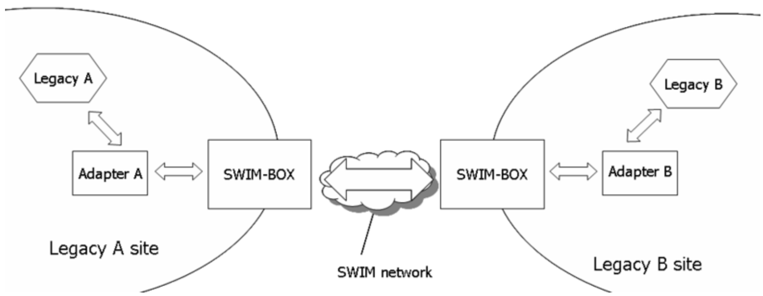


Figure 2. SWIM-SUIT prototype end to end connection.

1.2. The Swim-Box® Architecture

The Swim-Box® has been designed to achieve maximum flexibility both to introduction of new data exchanges and to changes in the underlying technologies.

The Swim-Box® supports the exchange of different kind of data (or Data Domains, according to the SESAR definition):

- Flight Data – represented according to the ED-133 EUROCAE standard (and supporting its CDM process);
- Surveillance Data – represented either in Asterix Cat.62 or custom XML;
- Aeronautical Data – provided by EAD (European Aeronautical Database) system according to the AIXM5 standard.

From a high level point of view, the Swim-Box® can be internally separated in two layers.

- A Data domain layer: in this layer reside specific components specialized in the support and exchange of each of the data domains that are managed by the Swim-Box®. Each of those components are independent from each other (both at compile-time and at run-time) thus allowing easy and flexible configuration and deployment.

- A core layer: in this layer reside components that are independent of the specific data that are managed by the Swim-Box®. Such layer provides "services" (or capabilities) to the components that belong to the upper layer. In this layer we can find components such as:
  - The Security Mediator: which provides encryption/decryption functionalities, authorization/authentication etc.;
  - The pub/sub service: which provides an abstraction of the underlying technologies and COTS that are used to implement the publish/subscribe pattern (thus allowing the system to easily exchange data using different COTS implementation or even changing technology from DDS – Data Distribution System – to JMS – Java Messaging Service;
  - Shared Data Store: an abstraction of a distributed cache that is used to synchronize limited amount of configuration data among the network of Swim-Boxes.

This high level system design is depicted in Fig. 3, which also illustrates the internal decomposition of the Swim-Box® into its two layers.

This logical decomposition may then result in different deployment schemas (each logical component may be deployed as a library, an Enterprise Java Bean, etc.). Still referring to (Fig. 3), the uppermost external interfaces are dedicated to the communication with the "local" Adapter, while the bottom ones are dedicated to the interactions with the other Swim-Box® instances. Only Swim-Box® instances are authorized to directly consume services on these interfaces.

The prototype has been designed with a modular architecture in such a way to ease the introduction of different specialized data domain components. Given this modular architecture each component may implement its own standard or technology. Of course, a uniform principle has been followed in defining the technology through which the interfaces are exposed, but, also in order to empirically test different solutions, various standards have been adopted (e.g. Web Feature Service, Web Service Notification, etc.).

1.3. Validations

The Swim-Box® prototype has been integrated with a large number of systems during the SWIM-SUIT project as well as in subsequent trials. It has been even used to allow the exchange of flight and surveillance data among Europe and US systems thanks to the collaboration with Boeing which provided its own SWIM test bed geographically based in the US.

Swim-Box® has been integrated with various SELEX Sistemi Integrati FDP systems (e.g. SATCAS and Coflight) as well as with Airport systems (e.g. Milan Malpensa and NATS Airport CDM systems), Airline Operating centres (e.g. Air France and Alitalia LIDO) and even an Alitalia A320 simulator.

2. Swim-Box® and SESAR

Swim-Box® has been developed and designed in the course of the European Commission FP6 SWIM-SUIT project. The success and significance of the initiative has been

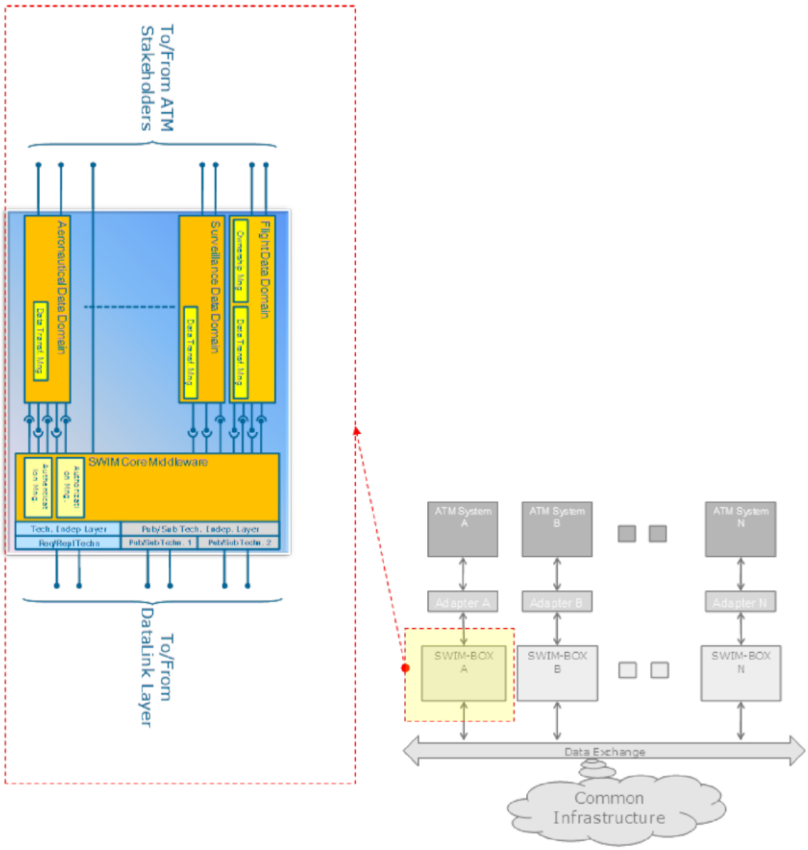


Figure 3. SWIM-SUIT high level system design.

fully recognized by SESAR which dedicated one specific project (P14.1.1) to evaluate the results and define what could be reused. SESAR has of course also introduced some differences. In particular, one of the main innovations introduced in SESAR is the concept of "SWIM Profiles" which are basically a means to group requirements so as to implement them (and serve the corresponding business needs) more efficiently through specific SWIM solutions. As a result, multiple SWIM solutions will be present in order to better suit those different sets of requirement. Currently three SWIM Profiles have been defined in SESAR:

- ATC-ATC profile: where Flight Object are exchanged according to the ED-133 standard;
- CFMU B2B NOP profile: where business clients can access the CFMU web services through internet;
- EAD B2B profile: where business clients can access aeronautical information provided by EAD through a generic publish/subscribe mechanism.

Also within this framework Systems/Applications access the SWIM Infrastructure via a "logical" entity which, in this case, is named SWIM Node, as shown in (Fig. 4).

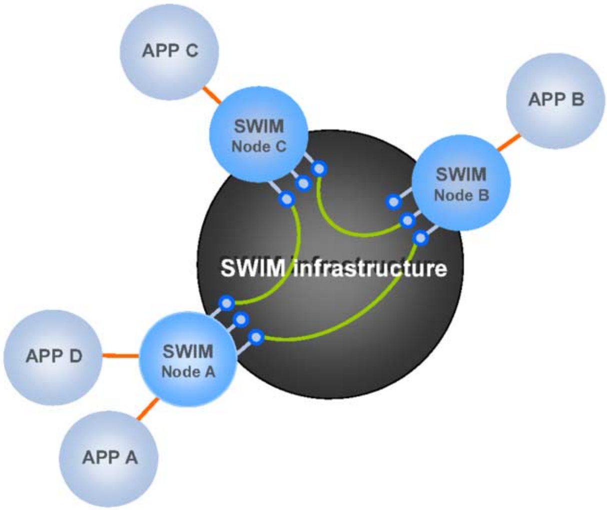


Figure 4. SESAR SWIM high level architecture from [5].

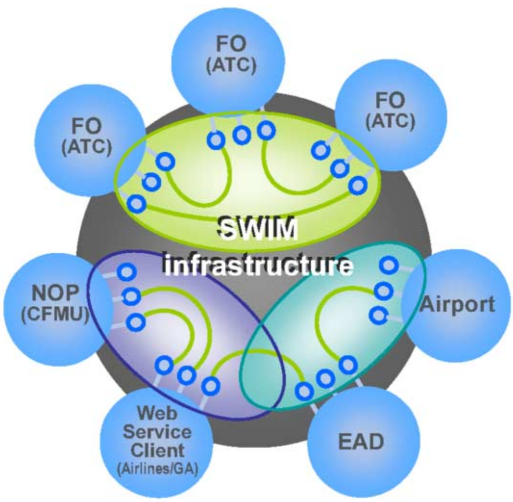


Figure 5. SESAR SWIM architecture with Profiles from [5].

Differently from SWIM-SUIT, the SWIM-Node can be either very light (e.g. a library on client side) or more complex as a mediator. This depends on which profile(s) the SWIM Node is supporting.

Therefore a situation like the one in Fig. 5 can be present (and has been experimented in SESAR for Step1) where the different circles represent different SWIM profiles. The implementations (and the requirements) of the SWIM Nodes belonging to the different circles are different since they serve different needs.

The Swim-Box®, according to the SESAR view, can therefore be seen as an instance of such a SWIM Node which is serving the SESAR ATC-ATC profile and supporting the SESAR EAD B2B profile.

Swim-Box® has recently been successfully used in the first SESAR SWIM demonstration (on November 16th 2011, in Bretigny, at Eurocontrol premises), in scenarios focused on the ATC-ATC and EAD B2B integration, demonstrating its interoperability with other SESAR partner implementations.

Participation to this first SWIM demo event is evidence of SELEX Sistemi Integrati's commitment to constantly aligning its Swim-Box® prototype to the specifications and innovations coming from SESAR.

References

[1] SESAR Consortium, The ATM Target Concept D3, pp. 36–38.
[2] ICOG IOP Interface Specification, Final Report 07/05/2008.
[3] FOIPS project homepage, www.eurocontrol.int/eatm/public/standard_page/foips.html.
[4] Eurocontrol, ASTERIX Cat 62 Ed.1.9, http://www.eurocontrol.int/asterix/gallery/content/public/documents/cat062p9ed19.pdf.
[5] SESAR Project P14.2.9, D03 deliverable "SWIM Technical Infrastructure Definition", version 00.01.02.

About the Authors

Dott. Giuliano D'Auria is SELEX Contribution Manager for SESAR
SELEX Sistemi Integrati
Via Tiburtina Km 12.100
00131 Rome, Italy
Tel.:+39 0641504448
gdauria@selex-si.com
www.selex-si.com

Eng. Dario Di Crescenzo is SESAR Work Package 14 co-leader and Technical Head of SELEX WPs B-8-14-16
Via Circumvallazione di Napoli, loc. Ponterccio c/o SELEX Sistemi Integrati
80014 Giugliano in Campania (NA), Italy
Tel.:+39 0818180273
ddicrescenzo@sesm.it

Eng. Antonio Strano is SESAR WP14.1.4 project Manager
Same address as above
Tel.: +39 0818180247
astrano@sesm.it

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-284

Contract-Based Air Transportation System (CATS) – A New Way of Managing 4D Trajectories

Christoph RIHACEK

Abstract. Contract-of-Objectives (CoO) is a specific tool in the context of trajectory-based Air Traffic Management (ATM), considering mutually agreed objectives between Air Traffic Control (ATC) entities, airlines and airports. This paper provides an overview of the CoO assessment performed during the CATS project and introduces the three Human-in-the-Loop (HIL) experiments carried-out in order to evaluate the concept of operations. Sufficient data were collected during the three experiments and analyzed in terms of system performance (i.e. safety, efficiency, and capacity) and human performance (i.e. workload, situation awareness, and acceptability). Final results show that controllers and pilots tend to accept the concept of operations and they prefer the approach of flying what was "planned, agreed and negotiated" during the planning phase, over the current principle, which is a "first come, first served" approach. Renegotiation of flight trajectories was considered as manageable, even with a traffic load extrapolated to the year 2020, without impact on safety. All actors participating in the validation exercises have recognized that implementation of CoO increases the amount of collaboration between crew and ground, as they share not only the same data, but also the same stable objective during the entire flight, i.e. the objective determined at strategic level through a Collaborative Decision Making process (CDM). Some additional Human Machine Interface (HMI) improvements are needed and also the task of calculating Target Windows (TWs) has to be refined. Airport and airline operators, as well as the network manager considered the renegotiation process to be feasible and acceptable. They acknowledge the principle of sharing the operational data of other actors as a great improvement in the way the decisions are made and validated.

Keywords. Contract of objectives, punctuality, airport, destination, target windows

1. Introduction

In recent years, Air Traffic Management (ATM) has permanently been on the move. However, there is one steady factor that will not change in the future: overall air transport will continue to grow, which introduces new demanding challenges. Considering the current ATM system, there is a clear need for more capacity, more efficiency and more safety.

As stated in the Single European Sky ATM Research programme (SESAR) documents [1], the future ATM system should be performance-based. It should bring together the ground and airborne segments more closely, should respect integrity of schedules and enhance interoperability. The air transport supply chain involves many different service providers, who very often are not aware of the overall target. At

present, the main actors mostly optimize their own processes locally in accordance with their own constraints and business objectives, but sometimes not considering the impact of their actions on the global system. In consequence, they do not always share the same objectives and sometimes even clearly counteract to each other. The promotion of highly collaborative and system-wide approaches seems to be a promising strategy to achieve overall system optimization, with opportunities for having variables and constraints that can be shared across the system. However, further R&D work is still required in order to evolve from a high-level concept to real operations, and also to evaluate impacts and prove the potential for real benefits.

2. Concept Overview

The purpose of the CoO is to create an operational link between all actors in the Air Transportation System (ATS) – airlines, airports and Air Navigation Service Providers (ANSP). The CoO represents a formal, collaborative commitment between all these actors. CoO defines the role as well as the tasks and responsibilities of each actor based on well-defined, agreed and shared objectives. These objectives represent the commitment of each actor to keep a particular aircraft inside temporal and spatial intervals denoted as Target Windows. These goals have to be agreed by all involved actors for specific transfer of responsibility areas, e.g. between two Air Control Centers (ACCs). As a consequence, each actor will be fully accountable for his own achievements. The ultimate objective of the CoO is therefore increasing punctuality at the destination, while improving the system efficiency and predictability through enhanced collaboration between air transport actors.

For a formalization of the CoO and its refinement for each local actor, a concrete manifestation of the CoO is proposed through the TWs. They represent a kind of a common language between all the involved actors, and also between the planning and operational phases.

Instead of precise 4D points, the TWs are expressed in terms of temporal and spatial intervals. They are located at the transfer of responsibility areas (Fig. 1). Their sizes and positions reflect the outcome of previously negotiated objectives, considering constraints, such as punctuality at the destination, runway capacity, congested en-route areas or aircraft performances. TWs provide sufficient room for manoeuvres to manage conflicts and ensure resilience in case of schedule disruption while imposing constraints only if necessary. Uncertainty will always be inherent in the system and can never be entirely erased. The CoO concept [3,4] proposes, instead of attempting to completely remove this uncertainty, to keep it under control by managing the disruption via adapting the sizes of the TWs, therefore limiting the side effects of any disruption. Divergence from this planning (either because of operational issues or due to uncertainty) still remains possible, but such divergence would just trigger a specific decision-making process – called renegotiation – at system-wide level.

These TWs are renegotiated utilizing a CDM process, aiming to achieve punctuality at the destination, while taking into account all actors' constraints. The life-cycle of this negotiation process (Fig. 2) can be described as follows:

- Long-term planning phase (years to months): development of an initial schedule, not overly detailed, comprising TWs at departure and arrival airports, taking into account infrastructural and environmental constraints;

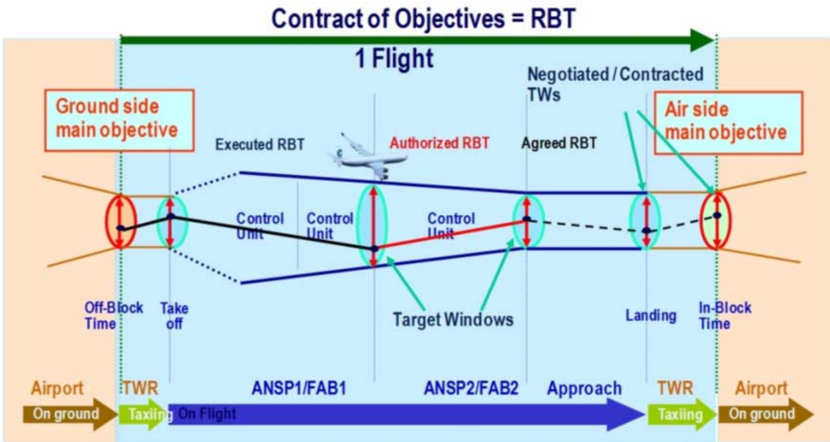


Figure 1. Contract-of-Objectives.

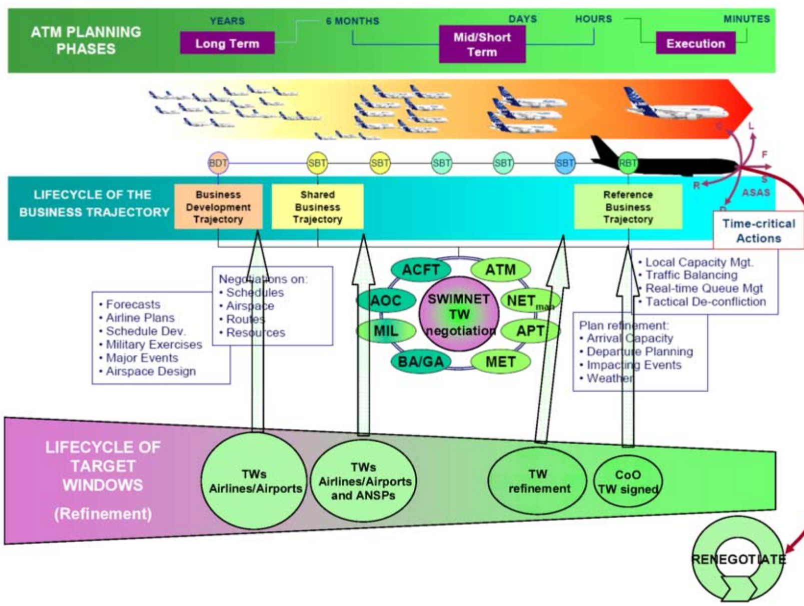


Figure 2. TW Life-cycle.

- Medium-term planning phase (months to days): development of business trajectories and negotiation of TWs through an iterative process; integration of weather predictions;
- Short-term planning phase (days to minutes before the execution phase): continuous refinement of the TWs up to the CoO signature.

The CoO provides the controllers and aircrew with a means required for managing the imprecision inherent in air traffic in accordance with their own objectives. Each crew's main objective is to adhere to an arrival schedule defined through the TWs.

Controllers, on the other hand, must ensure aircraft safety while keeping them within the envelope defined by the contract.

If for any reason one of the TWs cannot be fulfilled, a renegotiation process has to be started, involving the impacted actors and resulting in a new CoO.

Trajectory-based operations generally ensure that the actual trajectory flown by the airspace user is close to the planned one. The proposed Business Trajectory should go through these different TWs to ensure the system's predictability and overall efficiency. The overall ATM system has to be optimized to handle future traffic, and this is what the CoO and associated TWs will offer.

3. Validation Overview

The main aim of the CATS Project was to assess the operational impact of CoO and associated TWs by involving the major actors in the supply chain. The CATS consortium has been set-up to involve representatives of the main stakeholders of the Air Transportation System.[1]

The CATS concept assessment, following European Operational Concept Validation Methodology (E-OCVM) [5], comprised two different types of validation:

- Operational validation, which analyzes how the proposed CoO and the associated TWs impact the operators' performance regarding selected Key Performance Areas (KPAs) as defined by SESAR [1];
- Systemic validation, which highlights the CoO impacts for the overall ATS on safety and risk management, cost benefit, and legal consequences.

The operational validation comprises three Human-In-the-Loop (HIL) experiments, which focuses on different validation objectives:

- HIL-1. Evaluation of the impact of the CoO between Air Traffic Controllers (ATCOs) [12];
- HIL-2. Evaluation of the impact of the CoO between ATCOs and aircrew [13];
- HIL-3. Evaluation of the renegotiation process involving ATM actors (airlines, airports and ANSPs) [14].

4. Experiments

The hypotheses validated in the course of the three assessments were:

- CoO implementation allows for safe operations;
- Implementation of TWs ensures the respect of schedule;
- CoO is still manageable even with increase of traffic as expected in 2020 (with the same route structure);
- CoO execution and renegotiation do not impact ATCOs' and aircrews' performance and workload;
- TWs integrate flexibility to cope with uncertainty;
- Working methods offered to ATCOs and aircrews, as a result of the CoO implementation, are feasible and acceptable;

- Renegotiation of TWs is manageable for airport, airline and network manager staff;
- Collaboration between ATCOs and aircrews is high.

5. Experiment Variables

Two independent variables have been manipulated and monitored during the experiment: traffic loads and TWs (present/absent).

Two traffic loads were used during the experiments: current 2008 traffic level in the simulated area and forecasted traffic to 2020.

The reasons causing the renegotiation are manifold and may impact the extent and duration of the renegotiation process. For that reason, five different uncertainty events were intentionally introduced during HIL3 to assess the renegotiation process (e.g. airport closure, swap of slots, windshield crack, …) [15].

6. Measurements

During the experiments data were collected and subsequently analyzed regarding system performances and human performances.

The aim of the system performance evaluation was to assess whether the CATS benefits are delivered as proposed. From the stakeholders' concerns and the SESAR performance framework [6], four of the SESAR KPAs were identified as being potentially improved by CoO introduction: capacity, safety, efficiency, and predictability.

The aim of the human performance evaluation was to validate whether the contribution of the human to the overall system performance is within its capabilities (workload, situation awareness, working methods, feasibility, acceptability, etc.) and does not reach human limits. Human performance could be seen as an enabler to reach system performance.

Different methods and techniques were used to post-process the recorded data, such as observations, questionnaires and self-assessments.

7. Experimental Environment

The airspace chosen for the experiments comprised two en-route sectors (Milan MI1 and Geneva KL1) (Fig. 3). Five airports were selected for the renegotiation process. These airports were: Geneva, Zurich, Milano, Marseille and Lyon. The selection was endorsed by the team of experts within the project.

Controllers and pilots participated in the experiments. During the third experiment one network manager, one airline operational staff member and one airport operator staff member additionally participated in the experiment.

The simulation environment (Fig. 4) was composed of two coupled simulators and a CDM platform:

- ATM simulator: specific HMI for TWs display and associated tools were developed in the course of the project.

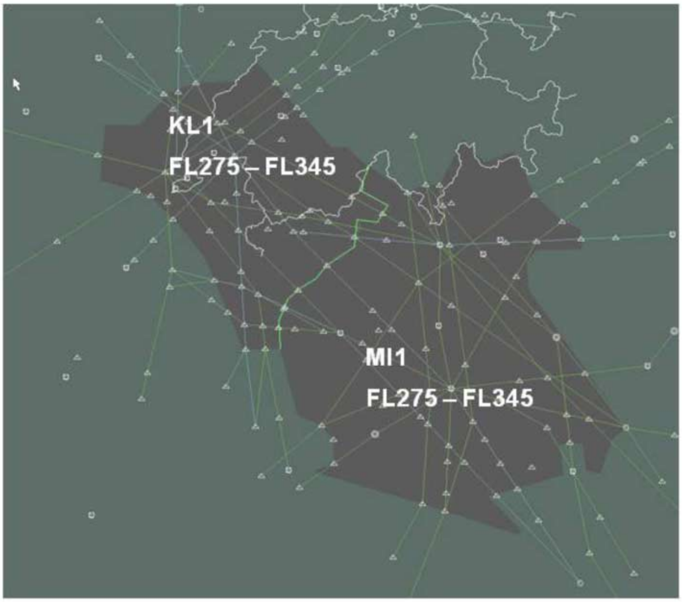


Figure 3. Measured Sectors.

Figure 4. HMIs and Simulation Room Display.

- Two A320 cockpit "flight simulator 2004": specific HMI for TWs display were developed on the Navigational Display.

In each run, four "flight simulator 2004" aircraft were piloted by the two pilots. The other aircraft were handled by automatic pseudo pilots that automatically executed the controller instructions.

- A CDM platform was designed for the renegotiation assessment. Specific mock-ups of an airline operational centre, airport command centre, and ANSP command centre were developed.

8. Results and Conclusion

The CATS project assessed a new ATM paradigm based on an innovative operational concept, the so-called Contract-of-Objectives. The CATS concept proposes a transition from means-based management of flights to performance-based management (through a contract-based system).

This paper explained the set-up and the evaluations made in the course of the three operational validation exercises in general. It did not addresses the detailed results of the operational validation [12–14] and systemic validation [7–11].

CATS selected a representative operational context for performing the three operational validation activities, involving representatives from key ATM players. A well-known and tested set of validation techniques and methods was selected and thus ensured confidence in reliability of the obtained results.

The objectives of the three HIL experiments were to assess the CoO concept and associated TWs, to investigate the impact of the CoO concept on controllers' and pilots' tasks and working methods, and to evaluate the operational acceptability from the actors' point of view (airport and airline operators, network manager) and operators (controllers and pilots).

The recorded data were then analyzed regarding human (i.e., workload, situation awareness and acceptability) and system performances (safety, efficiency, capacity and predictability).

The results demonstrated that the concept was perceived feasible and acceptable by the controllers and pilots, and the TWs were manageable, even with the 2020 traffic load, without jeopardizing safety. The potential benefits proved to be more relevant for airlines and the Air Transport System as a whole than for the individual actors. All actors recognized that implementation of the CoO concept will increase the collaboration between crew and ground, as they share not only the same data, but also visualize the same objective all along the flight. Actors and operators found the renegotiation concept fully manageable without major impacts on their activity.

Actors clearly acknowledged that having a CoO and the renegotiation process in place would improve the efficiency of the transportation system. All participants do agree on the principle of flying what was planned, agreed and negotiated (or re-negotiated), as opposed to the "first come first, served" approach. However, some additional HMI improvements are required to strengthen and optimize the proposed concept, mainly regarding the renegotiation process.

As a conclusion, the HILs results [12–14] showed that the CATS concept could be seen as a possible driver for implementing the SESAR Business Trajectory [2]. Moreover, the CoO assessments performed within the CATS project contributed to getting detailed understanding of the validation required for such complex concepts.

Endnote

[1] The consortium comprises the following members: Frequentis AG, EUROCONTROL Experimental Centre, Air France Consulting, L'Ente Nazionale Assistenza al Volo (ENAV SpA), Zurich Airport, University of Leiden, Swiss Federal Institute of Technology, Laboratorio di Ricerca Operativa Trieste University and Skysoft ATM.

References

[1] SESAR Definition Phase, Deliverable 2. Air transport framework – the performance target, www.sesar-consortium.aero.
[2] SESAR Definition Phase, Deliverable D3. The ATM target concept, www.sesar-consortium.aero.
[3] CATS Concept of Operations, D1.2.2, www.cats-fp6.aero.
[4] S. Guibert, L. Guichard, C. Rihacek, L Castelli and A. Ranieri, 2008, Contract-based Air Transportation System to fulfill the arriving on time objectives, in Proceedings of 26th International Congress of the Aeronautical Sciences, Anchorage, Alaska.
[5] EUROCONTROL. European Operational Concept Validation Methodology (E-OCVM) Version 3, www.eurocontrol.int/valfor/public/standard_page/OCVMSupport.html.
[6] Episode3, April 2008. Performance Framework, www.episode3.aero.
[7] CATS Report on the Selection of safety critical and risk sensitive case studies, D2.2.1.1, www.cats-fp6.aero.
[8] CATS Report on modeling and quantitative risk analysis, D2.2.1.2, www.cats-fp6.aero.
[9] CATS Report on Human in the Loop Effects, D2.2.1.3, www.cats-fp6.aero.
[10] CATS Report on Cost-Benefit Analysis, D2.2.2, www.cats-fp6.aero.
[11] CATS Report on Legal Assessment, D2.2.3, www.cats-fp6.aero.
[12] CATS HIL1 results analysis, D2.1.1, www.cats-fp6.aero.
[13] CATS HIL2 results analysis, D2.1.2, www.cats-fp6.aero.
[14] CATS HIL3 results analysis, D2.1.3, www.cats-fp6.aero.
[15] S. Guibert and L. Guichard, 2010, 4D Trajectory management through Contract of Objectives, in 9th Innovative Research Workshop & Exhibition, December 2010, Brétigny-sur-Orge, France.

About the Author

Christoph Rihacek
Senior Project Manager and CATS Project Coordinator
Frequentis AG
Innovationstrasse 1
1100 Vienna, Austria
Christoph.Rihacek@frequentis.com
www.frequentis.com

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-292

Managing Complexity

David PÉREZ

Abstract. The complexity of integrating different nodes, like airports, in a network paradigm shows that, in our society, an increasing number of socio-technical systems are formed by a large number of elements that need to interact with each other in a non-linear fashion to achieve a successful system performance. This kind of systems is called "Complex Systems", and their main characteristics are that they exhibit system-wide behaviours that emerge from the interactions and cannot be understood just from the information stored at individual level. Studying the air transport in general, and air traffic management (ATM) in particular, from the "Complex System" point of view, using new technologies and techniques, will help to understand different insights of the system performance.

Keywords. Complex systems, techno-social systems, complexity science, resilience, disturbance propagation, system stability, system agility

1. Why Complexity Is Becoming an Important Research Thread to Techno-Social Systems?

Complex Systems Science is one of a number of names given to the study of Complex Systems, also known as Complexity Theory, Complex Systems Theory or Complexity Science. This kind of systems can be defined as the collection of a high number of parts (elements, individuals, agents…) that interact in a nonlinear fashion, such that the system exhibits behaviours at the system-wide level that emerge from the combined actions of individuals within the system (emergent behaviour) and cannot be understood only from the information stored at the individual level. Complexity Science tries to understand how these interactions can create that collective emerging behavior; and this is not a trivial task, as emergence carries with it the additional implication that these phenomena typically cannot be predicted by examining the individuals' behaviour alone. Complexity Science provides us with methodologies and tools aimed to understand the mechanisms that govern such emergent behaviors, and to reduce their negative impact, while taking into account the role of uncertainty: where it arises, and how it should be taken into account.

To better illustrate this concept, the reader may think on those many natural and man-made systems, working for significant periods of time close to a critical point. For instance, the power transmission network: from time to time, blackouts occur, in some cases affecting millions of peoples [2]. Or the transportation networks of many cities: during peak hours, jams frequently block the movements of cars and buses [3]. These two systems, as well as many others, share a number of characteristics, the most important one being that system failures are usually a consequence of small and localized problems, which spread across the entire network (for instance, an overloaded low voltage line, or a single car accident). The air transport network suffers similar issues. Technical problems, or adverse weather, may generate delays at one airport of the network, which then propagate to other airports and result in a major disruption in the Eu-

ropean Air Transport Network. This feature, which is in most cases undesirable, is called self-organized criticality: forces inside the system interact to drive it to a situation close to a critical point; and this global behavior, that is, this self-organized criticality, is indeed the result of the interactions between all the elements of the system: in other words, an emergent behavior. In those systems, any external, but also internal, disturbance can lead the system beyond that critical point, generating a major disruption [4].

Human minds are not good at accepting uncertainty and system complexity aggravates uncertainty. Many scientists have operated under the false belief that their mathematical tools could eliminate uncertainty, but, from the complexity science perspective, this cannot be achieved. The study of complexity will not lean on a single theory, but is, on the contrary, highly interdisciplinary and encompasses a set of ideas, methodologies and tools from different fields, such as nonlinear dynamics, statistical physics and numerical simulation.

The field of complex systems was for the first time recognised as such in the article "More is Different", written by the Nobel laureate physicist Philip W. Anderson in 1972, whose title refers to the concept of emergence [1]. Anderson maintains that the traditional reductionist view of science is incomplete, because complex systems show behaviours that are qualitatively new and different from those of the sub-units from which they are made. Moreover, it is not possible to predict the behaviour of a complex system starting from a knowledge of its constituents (e.g. from the behaviour of a small number of electrons it would be impossible, or at least impossible in practice, to predict in advance the experimental observation of the phenomenon of superconductivity, which occurs only with very large numbers of electrons). Nevertheless, it was in the 90's when the development of computer science boosted the study of Complex Systems and Complexity Science began to be applied to the study of a broad range of large socio-technical systems.

2. Air Transport Complexity

The air transport system contains a huge number of elements or agents that interact, e.g. tenths of thousands of daily operations in Europe, heave fragmentation in processes throughout the network, a fairly complex information flow, a very large number of stakeholders involved in the decision making process and pervasive heterogeneity in users goals and business requirements.

Most effort done so far in air traffic modelling and design has not taken into account this paradigm, and thus it has failed to model such emergent behaviour. Complex systems techniques can provide a new insight into the understanding of these phenomena and help overcome some of the limitations of the current models. A number of recent, novel approaches to ATM modelling are currently borrowing tools and techniques from the Complex Systems field. However, the literature in this field is still scarce.

3. The ComplexWorld Research Network

ComplexWorld (www.ComplexWorld.eu) is a research network within SESAR WP (Work Package)-E and led by The Innaxis Research Institute (www.innaxis.org) that

aims to organise the research on the applicability of state-of-the-art Complex Systems Science methodologies with the main general objective of advancing in the understanding of the behaviour of the ATM system, as a necessary step prior to improving its overall performance.

The Network also counts the Universities of Seville, Westminster, and Palermo as well as DLR and NLR as members and has signed up more than 70 organisations coming from industry, research and academia. This multi-disciplinary group is tackling the following Specific Research Challenges:

1. Understand how Complexity Science can contribute to understand the ATM system behaviour and evolution that emerges from the complex relationships between its different elements.
2. Identify relevant sources of uncertainty in the ATM system, which includes the analysis of its different scales, and understand the propagation of uncertainty through the different scales.
3. Research how Complexity Science can improve the overall performance of the system in different key performance areas, in particular, learn how this could bring new methodologies to manage uncertainty and increase predictability.
4. Study the propagation of undesirable events through the network, designing strategies to minimize the impact of such perturbations and ensure a customer-friendly degradation of mobility inside Europe.
5. Understand how to design a more agile system, through the development of new methodologies to the implementation of new technologies, easing transition phases, optimizing performance during those transitions and enabling innovation.

4. Making a Difference in Air Traffic Management

The scientific revolution made us feel that we were in possession of tools that would allow us to grasp the future, however, the limits that non-linearities put on forecasting in air transport needs to be researched at different scales. In particular, the sensitivity to initial conditions is an important field to understand the variability of ATM performance along different days of operations with small variations in the initial conditions. Some behaviors will remain unpredictable and therefore we need to adjust our existence, rather than naively try to predict extreme events.

5. Resilience, Analysis of Disturbance Propagation and System Stability and Agility

Complexity Science research has applicability in a number of ATM-related subjects. Resilience, robustness and analysis of disturbance propagation and system stability and agility is one are in which the ComplexWorld network is looking into.

The Air Transport System is constantly influenced by internal and external events. Every day, several times each day, and in different locations at the same time, the operation of the system is perturbed by the small disturbances. Even worse, these disturbances may interact with each other, creating a cascade of adverse events that may span over different spatial and time scales, from affecting only one aircraft or a crew, up to a group of airways crossed by a thunderstorm; but, at the same time, they usually have

small impact in the overall performance of the system, thanks to its own Adaptability – aircraft and crews may be rescheduled, flights may be rerouted, and so forth.

A complementary problem is represented by those events that push the dynamics of the Air Transport System far away from its normal point of operation. For instance, a large strike, the eruption of a volcano, or the closure of an airport dramatically affect the performance of the system. Note that these events are not small disturbances, affecting a single or a limited number of aircraft: they have system-wide consequences; moreover, these events were not predicted nor expected, and the process to go back to a normal operation is not trivial. Luckily, these black swan events are quite rare: but this low probability of occurrence also makes any analysis more difficult.

6. Conclusion

The Air Transport and ATM have experienced an important and fast evolution in the last decades, with a constant growth in the number of flights, aircraft and airports. Also, the market itself has changed significantly: from being composed by a small number of national airlines, up to the recent appearance of many companies with new business models.

In this context, the optimisation of common airspace resources, along with more strict safety regulations, has reduced the ability of some actors to optimise their operations, thus reducing the adaptability of the system. Even the definition of which events are "normal", that is to say, taken into account in the design of the system, is not a trivial problem: and this is worsened by the ever changing nature of the ATM – an event may be extremely rare today, but not so rare tomorrow.

References

[1] Anderson, Science 4 August 1972, Vol. 177, No. 4047, pp. 393–396, DOI: 0.1126/science.177.4047.393.
[2] B.A. Carreras, D.E. Newman, I. Dobson and A.B. Poole, IEEE Transactions on Circuits and Systems I: Regular Papers, Sept. 2004, Vol. 51, No. 9, pp. 1733–1740.
[3] K. Fourrate and M. Loulidi, The European Physical Journal B – Condensed Matter and Complex Systems, 2006, Vol. 49, No. 2, pp. 239–246.
[4] W.I. Newman1 and D.L. Turcotte, A simple model for the earthquake cycle combining self-organised complexity with critical point behavior, Nonlinear Processes in Geophysics, 2002, Vol. 9, pp. 453–461.

About the Author

David Pérez is Director of the Innaxis Research Institute
Velasquez 157, Ibercenter
28002 Madrid (Spain)
dp@innaxis.org
www.innaxis.org/dp

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-296

Advanced Flexible Automation Cell

Philip WEBB and Seemal ASIF

Abstract. The “FLEXA” (FLEX AUTOMATION CELL) project here below presented aims to overcome the reasons for which there is so far relatively little use of automation in aerospace manufacturing. How? By combining a number of different technologies and methodologies, specifically: system architecture and design, knowledge engineering, virtual verification and quality assurance, cell integration, human integration and restart.

Keywords. Automation, manufacturing, flexible manufacturing, programmable logic controller, service-oriented architecture

1. Introduction

There is relatively very little use of automation in aerospace manufacturing when compared with other industry sectors such as automotive, pharmaceutical or white goods [1]. There are a number of reasons for this. The product volumes tend be relatively small but the product lifecycles may be in excess of 30 years. The parts used are usually required to be to a very high standard of quality and all the associated processes need to be traceable and verifiable [2]. The variety of parts is also very high and this low volume / high variety mix means that a large number of conventional automated systems would be required but each would then have a very low utilisation rate and therefore be uneconomical. A further and significant complication is that in operations such as turbine blade repair the manufacturing requirements are not known until the process has started. The FLEXA (Flexible Automation Cell) project aims to overcome these problems by combining a number of different technologies and methodologies to the problem. Specifically:

- System architecture and design;
- Knowledge engineering;
- Virtual verification and quality assurance;
- Cell integration;
- Human interaction and restart.

The work described in this paper focuses on the knowledge engineering theme within the project that enables the deployment of multiple machines or resources in a flexible and reconfigurable environment.

2. Background

The Flexible Manufacturing System (FMS) was developed to overcome some of these issues through the integration of automated component storage, tool delivery and CNC

Figure 1. Large Scale Part Assembly Cell.

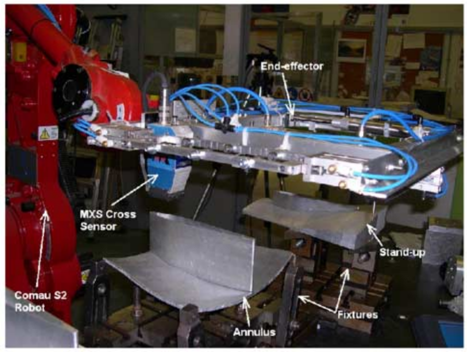


Figure 2. Small Scale Part Assembly Cell.

machines with an overall computer control unit to support and monitor the performance of the system. In many cases these FMS installations have been very successful; however in some cases the flexibility has been very low when trying to produce a wide variety of changing components within existing cells. For example in a blade repair facility there is both a wide variety of parts and the actual process route required is not known until the process has started and the blades have been inspected. In the case of aero-structure assembly the problem becomes even more complex. Because of the very large parts and assemblies involved the automation (robots) must be moved to the part rather than the conventional approach of moving the parts between individual cells or along a flow-line. This means that multiple processes are likely to be performed using the same processing equipment but in different locations; to enable this, a new approach to cell control and organisation is required. For example a robot may be used for drilling in one part of the factory and then used later for applying sealant in a completely different part of the factory. Examples of large and small scale part assembly cells are shown in Figs 1 and 2 respectively.

3. The FLEXA Cell Coordinator Architecture

The heart of the control architecture proposed is the FLEXA Cell Coordinator (FCC). The methodology for control and organisation being developed makes two assumptions about the process and the production resources being used. They are as follows:

- Production is assumed to be chaotic due to the number of processes and the likelihood of concessions needing to be cleared and in the case of repair the process sequence is not known until the part has been inspected;
- The resources (robots, machine tools etc.) can be used in different sequences for different operations either by physically relocating them or changing the root of a part through the resources.

The issues noted above mean that the use of a conventional control methodology using a Programmable Logic Controller (PLC) and a number of machines (resources) physically coupled together running preloaded programmes is impractical as in the cases above the individual cells would need to be physically reconfigured for each operation. A new way of approaching this problem is to use a central cell controller which is capable of producing any number of virtual controllers each of which can take control

of local groups of machines to form virtual cells which then behave like conventional physical cells. These sub-coordinators are software applications tied to their resources using a common interface. The overall cell controller is responsible for decoding recipes (which contain all the process information), allocating and scheduling resources and launching and destroying instances of the sub-controllers when required. It also contains a database which is used to store status information to allow recovery of system status in the case of an equipment or process failure. In summary:

- The use of a software Programmable Logic Controller (Soft PLC) means that there is no longer any physical hardware associated with the cell;
- All the production systems for example machine tools, robots or measuring systems are classed as networked resources which have a common interface which allows them to be interrogated and identified automatically;
- When a particular production sequence is identified a 'recipe' is generated from which the required resources can be identified, allocated and programming information loaded;
- The resources are co-ordinated using a soft PLC which is connected to the resources over a network and has no exclusive hard wired links to any of the resources;
- The overall control is provided by a cell co-ordinator which allocates a virtual sub co-ordinator for each cell;
- Once the task is finished then the virtual cell sub-coordinator is closed down and all the resources are freed up and made available for other tasks that may be waiting for resources.

A diagram showing the structure of the cell coordinator is shown in Fig. 3. The individual elements have the following functions:

3.1. Application Manager

The Application Manager is responsible for the control of the FCC. The Application Manager has responsibility to activate the FCC and communicate between the FCC's components. The Application Manager also has responsibility to communicate with the rest of the world via the web services layer.

3.2. FLEXA Scheduler

This is needed to schedule the task among resources. The Scheduler will be able to identify the available resources and will allocate the task to them according to the recipe (sent from FDB). The Scheduler will also be able to resolve and avoid conflicts (Deadlocks, etc.).

3.3. Status Data Base & Monitor

The Cell coordinator status database is used to record the status of the resources and the availability of resources (if they are free for handing over to a task). The status database monitor has active two way connection with the status database monitor which monitors all the activities of the resources and records the status of all the current recipes.

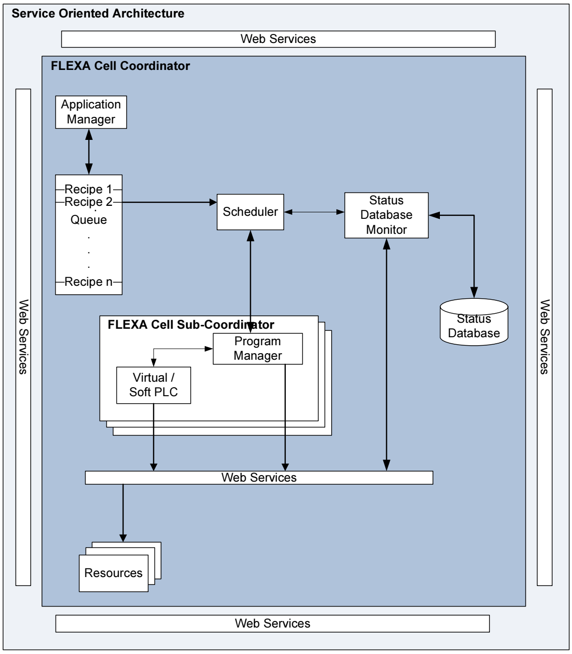


Figure 3. Flex Cell Coordinator Structure.

3.4. Recipe Queue

The Recipe Queue accepts the request from the Application Manager to execute a particular recipe, if there is one present. The recipes will be sent out for execution by the scheduler on first come first serve basis.

3.5. Cell Sub-Co-Ordinator

The Cell Sub-Coordinator is comprised of a Program Manager and the Soft PLC. The program manager receives the recipe from Scheduler and delivers programs to the resources(s). The Soft PLC also takes its program from Program manager and controls the resource(s) accordingly. There can be multiple FLEXA Cell Sub-Coordinators all of which will be controlled by the Application Manager. One sub-coordinator will work with one set of resources and each other one will use a different set of resources.

4. Design of the Cell-Coordinator

The biggest challenge in designing a flexible control system with varying cell resources is to design a loosely-coupled structure without losing efficiency and yet the system should also be easy to reconfigure and extend. Since the cell resources usually come from different manufactures and use different platforms and communication protocols the traditional distributed computing technologies such as COM (Component Object Model), could lead to too tightly a coupled relationship between cell resources. Any

changes to the system such as a newly installed metrology system may need some alterations within the original software which significantly reduces flexibility and reconfigurability [3].

It was therefore proposed that a service-oriented architecture (SOA) would be more efficient. An SOA uses a web service as the basic element. This was originally designed to support interoperable machine-to-machine interaction over a network [4]. A web service is platform-independent as it uses the standardized Simple Object Access Protocol (SOAP) as its communication protocol [6] and the XML format as its message exchange format. As a result, any device that supports TCP/IP communication can be programmed to provide a web service which greatly reduces the complexity of communicating with different platforms and environments.

Web services perform functions and actions which can be anything from simple function requests to complicated processes requests. Once a Web service is deployed, other applications (and other Web services) can discover and invoke the deployed service which makes service-oriented architectures naturally support plug-play. As web services are loosely coupled and have a generic communication protocol and data format, they can be easily deployed within a distributed system. Therefore a Service Oriented Architecture has been used to realise the FCC.

5. Cell Co-Ordinator and Testing

The core FLEXA Cell Sub-Coordinator has been fully realised using web-services in C#.NET and its basic functionality demonstrated using Comau robots as resources. The system has so far been shown to be capable of decoding a loaded recipe and:

- Selecting from the available web services which resources are needed for the recipe (further work is in progress to use advanced algorithms within the scheduler to optimise this process);
- Selecting the program needed to be run on the resource, detecting the resource and transferring the program on the specified resource;
- Continuously monitoring the resources for any information being fed back to other resources;
- Checking that the program has been successfully transferred to the resources and run.

6. Conclusions

So far the FLEXA Cell co-ordinator has been demonstrated using fairly simple scenarios based on robots and metrology. Within the next stage of the project the controller will be linked with a database and scheduling software being developed elsewhere within the FLEXA project. When this is completed the controller will be tested using much more complex and demanding scenarios. Further web services are being written to support a wider range of production resources to allow more complex recipes to be executed.

References

[1] N. Jayaweera and P. Webb, “Adaptive robotic assembly of compliant aero-structure components”, Robotics and Computer Integrated Manufacturing, Vol. 23, No. 2, 2007, pp. 180–194.
[2] N. Jayaweera, P. Webb and C. Johnson, “Metrology Assisted Assembly of Fabricated Aero-engine Components”, Assembly Automation, Vol. 30, No. 1, 2010, pp. 56–65.
[3] J.N. Pires and J.M.G. Sá da Costa, “Object-oriented and distributed approach for programming robotic manufacturing cells”, Robotics and Computer Integrated Manufacturing, Vol. 16, No. 1, 2000, pp. 29–42.
[4] T. Aphrodite and P. Thomi, “An overview of standards and related technology in Web Services”, Distributed and Paralleled Databases, Vol. 12, No. 3, 2002, pp. 135–162.

About the Authors

Professor Philip Webb
Cranfield University, Cranfield
MK 43 Oal Bedfordshire, UK
p.f.webb@cranfield.ac.uk
www.cranfield.ac.uk

Seemal Asif
Cranfield University, Cranfield
MK 43 Oal Bedfordshire, UK
seemal.asif@cranfield.ac.uk
www.cranfield.ac.uk

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-302

ACCENT: Adaptive Control of Manufacturing Processes for a New Generation of Jet Engine Components

Ignacio FERNANDEZ

Abstract. High responsibility of critical parts are those whose failure could lead to the lost of the aircraft. Manufacturing of critical parts for aero-engines turbines involves additional requirements in order to preserve the lifing of the part. Basically, the driver of these requirements is to maintain the characteristics of the parts used during the certification of the engine, in such a way that materials properties and/or testing employed will be applicable during the whole life of the engine. The European Commission has funded several projects within various Framework Programs in order to achieve competitive manufacturing methods increasing the safety of the parts at the same time. The ACCENT project, here after presented, is one of them.

Keywords. Manufacturing, engine components, surface integrity, lifing, failure, LCF (Low Cycle Fatigue)

1. Introduction

The current scenario for the aviation gas turbines market is based on Flight Hours Service (FHS) contracts, where the benefit for the manufacturer comes from the number of maintenance free flight hours instead of the aftermarket. This new scenario gives an additional importance to the lifing of the components, especially those which define the total life of the engine.

Now, the aim of the design is to extract more cycles from the component under study, at each new engine generation requirements are driving a reduction in the margin for the error, as parts cannot stand any drop in properties. Thus, the lifing procedures are refined by means of new models or additional specific testing for limiting features to increase the life of the components; however the scatter in material properties will also be reduced to always maintain safety.

Conventional machining can modify the LCF (Low Cycle Fatigue) curve of the components, and therefore the scatter, when abusive machining is present either by a wrong selection of the parameters or anomalies occurring during the process. This situation can produce hazardous failures of critical aero engine component during their life. The Pensacola event in 1996 was the result of such a failure (Fig. 1). Subsurface damage caused by a drilling defect resulted in the loss of 2 lives and one serious injury. Had this failure occurred in flight the consequences would have been disastrous?

The Federal Aviation Authority sponsored project ROMAN recommends the use of process monitoring for the manufacture of high length/diameter ratio holes. A subsequent European GROWTH project MANHIRP, investigated the production of manu-

Figure 1. MD88 Pensacola accident – 1996.

facturing induced anomalies. These projects however fail to deliver the necessary technological step required by the aero engine manufacturers in order to manufacture their most critical aero engine components whilst being faced with an ever increasing demand for engine performance, better engine efficiency, more environmentally friendly products, and lower cost of manufacture given today's competitive environment.

Nowadays, the previous demand will be satisfied delivering the necessary technological step required by the aero engine manufacturers in order to face the current ramp up in production and lower cost of manufacture given today's competitive environment.

2. Who, Where and When Is "ACCENT"?

In ACCENT are present the main European OEM of AERO gas turbines, as well as, universities and institute across Europe (Fig. 2). In general, the universities are matched with an OEM to perform the different machining trials and experimentation, although other universities provide a global support in very specific matters such as mathematical modelling and analysis. Another interesting point is within the OEMs leaders, there is a balancing between persons coming from manufacturing and those others coming from materials side. This also provides completely different perspectives of the same problem. Regarding the timing, initially it was a three year project starting in July of 2008, however, set up was complicated for some operations (broaching) and long time consuming in other operations (turning) and it was request for a 9 – month extension to properly finish the work. Besides extensive metallurgical and signal processing, longer than expected, is required to obtain reliable correlations.

3. What Is "ACCENT"?

ACCENT can be explained as the natural extension of MANHIRP, Manufacturing to Produce High Integrity Rotating Parts for Modern Gas Turbines which was a 5th framework project. MANHIRP provided very worthwhile information about the penalties in terms of LCF drop of properties due to unsuitable machining conditions. MANHIRP in summary provided us with two very important lessons:

Figure 2. Participants in ACCENT.

- Non standard machining conditions affect Surface Integrity (SI) of the parts which leads to a substantial penalty in LCF properties. This changes the lifing of the parts.
- Despite what many people think, peening is not the magic operation which recovers all the possible machining damage. In fact, where machining has generated heavily sub-surface damage, peening accelerates the initiation, compared to the same conditions without peening, and therefore reduces the LCF life.

A couple of terms have been mentioned that are very important in the context of both ACCENT and MANHIRP, Surface Integrity and Lifing. So, let looking a little bit deeper at these terms:

The parts of a gas turbine are usually classified in several categories according to two factors, the probability of the failure and the consequence of the failure. Each company has its own rules but by simplifying it they be divided in three groups; class A or critical parts where the failure could lead to the loss of the aircraft, class B or sensitive parts, which failure could lead to loss of the engine power and the rest which can be grouped into class C or unclassified parts. ACCENT is focused in class A parts because of the criticality of the failure and therefore the manufacturing conditions are controlled more tightly. The lifing of the part is the key aspect in the design, and the whole manufacturing process needs to be aligned in order to achieve the declared life. Although other aspects such as; creep, integrity, etc.…, need to be checked, the discs are designed against fatigue which is the failure mode. This is the reason why the LCF properties mentioned before are so important for these components.

The lifing of parts coming from spin rigs and/or sub-components, needs to be guaranteed along the whole production life for each specific part number, this is checked through the Surface Integrity of the parts. The Surface Integrity is a wide term to put together all features which can affect the LCF properties of the component, basically; surface roughness, micro-structural analysis and residual stress distribution. Some of them can be analyses by means of NDT, however others require the cut up and destruction of the part and therefore cannot be evaluated in all production parts.

Figure 3. Relationship between Lifing, Surface Integrity and Signals.

ACCENT will try to find an indirect way to control the quality of each production part by monitoring the process. The focus of the study is the relationship between Surface Integrity and signals, together with the knowledge coming from Manhirp the loop can be closed and it is possible to predict the life of the parts from the signals captured (Fig. 3).

4. Why "ACCENT"?

Surface Integrity of the testing for certification needs to be guaranteed in all the parts manufactured against this standard. However, the current methodology to demonstrate compliance with certification along the part life it is based on fixing the Method of Manufacture (MoM) used during certification. Those machining conditions will be called frozen parameters. This methodology shows two main problems:

- From a manufacturing point of view, changes require costly validation trials. So this leads to old machining conditions in production because the change is not economically viable due to the trials. In other occasions, inserts are so old that they do not exist in the market anymore and it is compulsory for to manufacturer to go through the validation process. So, in summary machining conditions are not always the best practices in the market.
- From safety point of view, it is impossible to ensure that validation part is equivalent to all the future machining parts of the same standard because of the destructive validation method used. It is true that scatter factors deal with the differences within the standard machining conditions, however undetectable abusive conditions could be present within the manufacturing, such as; excessive insert degradation, machining disturbances … etc., which could lead to unacceptable Surface Integrity.

Being aware of these premises, the current solution is to move away from the abusive machining conditions that generate such damage.

The proposed methodology is based on defining a safety window in which variations will be within an equivalent surface condition during the validation stage. Furthermore, trials will be monitored in order to identify the relevant signals which reveal anomalous behavior from a Surface Integrity point of view. These will be captured to monitor the production parts, and whenever a problem during production appears, it can be identified it and corrected, changing parameters within the safety window in order to obtain an acceptable part. Even though correction would not be feasible, the fact of removing defective parts from engines is in itself a great benefit.

Certification authorities already recognize Monitoring as NDT, which provides an extra credit in lifing calculation whenever is put in place in production. Currently, it is focus in power monitoring during hole making operations. ACCENT main purpose is to obtain a full understanding, with the current techniques of the monitoring capability.

5. How Is "ACCENT" Carried Out?

A suitable set up for each machining operation will be established in order to measure forces, accelerations and acoustics emissions, as well as internal signals coming from the machine such as power, torque… In some cases additional sensors have also been applied to measure temperatures for example. A good arrangement of the sensors is vital for a reliable data. The creation of the operating window is another key point, as there is not a method to establish the limits of a safety zone and window, thousands of trials could be required until a final solution can be found. A key point is to perform trials at both sides of the border to check whether the system is reliable to capture the differences. On this subject, each partner has followed their own strategy in order to find out which could be the best approach in this point. Thus, from DoE to modified COM methods have been proved.

The success of the project is based on being able to develop a two-way relationship between the signals and the Surface Integrity. Trials have been carried out with combinations of different machining operations (turning, milling, drilling and broaching) with different materials (Inco718, Ti64, Udimet720 and Ti6242).

Apart from that, it is also researching the effects of the different machining parameters on the Surface Integrity, which will provide a better understanding of the machining process from a lifing perspective. Regarding prediction models, different attempts have been tried but Neuronal Network has finally been selected.

Finally, all the research should be contained in a procedure, which defines an appropriate method to carry out the trials, the inputs required for the trials and the analysis of the results, in order to work with signal monitoring as a method which can improve the lifing of the parts and/or reduce the amount of destructive testing required.

About the Author

Ignacio Fernandez works at Industria de Turbopropulsores (ITP) in the Material and Process Department as specialist in machining of critical parts
Ignacio.fernandez@itp.es
www.itp.es

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-307

The European Project "Aircraft Integrated Structural Health Assessment II"

Detection of Corrosive and Hydraulic Liquids by Gauges Based on the Collapse of Percolation Conductivity

Helge PFEIFFER and Martine WEVERS

Abstract. Nowadays aircraft inspection procedures are well-elaborated, but also expensive in many cases. The reason is that scheduled inspections are time-consuming and they seldom provide information on actual structural damage. "Structural Health Monitoring (SHM)" would be an interesting option to tailor inspection to the real needs of aircraft operations. Within the so-called "AISHA II" project, advanced solutions are being developed and a special focus is on development of solutions with a relatively high technology readiness level. The permanent sensor networks proposed are based upon ultrasonic and upon electrical and electromechanical impedance measurements. They are described in this paper, as well as a new sensor developed at the Department of Metallurgy and Materials Engineering, Leuven, Belgium, which uses the loss of percolation conductivity in a composite.

Keywords. Structures, health, monitoring, percolation, conductivity, ultrasonic measurements, electrical & electromechanical impedance measurements

1. Introduction

In general terms, a SHM system is a permanent sensor network for detecting structural damage that is embedded on or into structural components of engineering structures. Whereas, some related commercial applications already exist for military airplanes (acoustic emission and strain monitoring), real SHM in civil aircraft is still in an experimental phase. There are different obstacles that have prevented an implementation so far. The main reason is that a complex research and implementation effort is required and expertise from many disciplines is needed that has to be coordinated in interdisciplinary projects. Thus, during the last two decennia, different SHM solutions for civil aircraft were developed, but most of them just on laboratory scale.

Within the European project "Aircraft Integrated Structural Health Assessment II" (AISHA II) advanced solutions for SHM in aircraft are developed and a special focus is on the development of solutions with a relatively high technology readiness level (TRL). The permanent sensor networks proposed are working on the base of ultrasonics as well as on electrical and electrochemical impedance measurements. For the case of ultrasonics, guided waves are used. For the reliable defect detection with guided ultrasonic waves, such as Lamb waves, mode conversion effects are applied and detection is performed by dedicated sensor arrays. An interesting option is accurate time-of-

flight detection of Lamb waves using the chirp technology. The sensor networks based on ultrasonic technologies were implemented in helicopter tailbooms, slat tracks and aluminium sheet structures. Another concept, already successfully applied, is the interruption of conducting wires by fatigue cracks (slat tracks and aluminium sheet structures) or by leaking liquids (floor beams and hydraulic tubes). Furthermore, electrochemical and electric impedance measurements are used to detect corrosion in floor beams and cracks in doubler repair. For alls technologies proposed, investigations of durability and robustness is a major concern.

When preparing the AISHA II project, the AISHA consortium (a SHM-project in the 6th Framework Program) was extended by 7 new partners in order to include new complementary expertise, especially from departments of maintenance, repair and overhaul (MRO). The consortium is now co-ordinated by the K.U.Leuven and the partners are METALogic (Belgium), DLR (German Aerospace Centre), Cedrat Technologies (France), Eurocopter-Marignane (France), Riga Technical University (Latvia), CTA (Spain), Meggit-Ferroperm (Denmark), ASCO (Belgium), Fraunhofer Institute IFAM (Germany), University of Leipzig (Germany), University of Basque Country (Spain), Free University of Brussels (Belgium) and Lufthansa Technik (Germany).

A more detailed report is given on a sensor developed at MTM that uses the loss of percolation conductivity in a composite. Using this sensing material a sensor for the floor structure was developed in order to detect corrosive liquids. The strong enhancement of resistance after the ingress of liquids can be recorded in different manners. Finally, after all feasibility tests performed in the lab, the sensor network was implemented in an operational airliner of Lufthansa.

2. Full-Scale Parts for the "AISHA II" Project

Relevant full-scale structural parts were selected to develop SHM systems with a high chance for final implementation. In this context, it is important to focus on real structural hot-spots where damage is very likely to occur. Focussing on hot-spots is also necessary because monitoring of very big surfaces like integral fuselages is not yet be feasible with the technologies available so far.

2.1. Slat Tracks of AIRBUS A320 and A380

The task of the slats is to increase the wing area of aircraft to provide additional lift during take-off and landing when the plane moves at relatively low air speeds. Slats tracks are the moving beams that enable the load transmission and movement between wings and moving slats. Slat tracks are under high fatigue loads when transferring lift and drag from the slat to the fixed wing, moreover, many kinds of environmental degradation (salt, sand and dust, kerosene, hydraulic fluids, etc.) will affect the structural parts. Two concepts for crack detection are essentially followed within the AISHA II project, the analysis of ultrasonic waves (especially Rayleigh waves) that have passed the crack area [1], and the interruption of electrical contacts in implemented crack propagation gauges. In contrast to the commercially available crack propagation gauges that allow the determination of various crack sizes, the AISHA II sensors are optimised to give information on those selected crack sizes when safety relevant dimensions are reached. At the moment the sensor is optimized concerning sensor length, crack gauge material and implementation procedure.

2.2. The Tailboom of the Helicopter Mil 8

The tailboom of a helicopter is used to connect the fuselage with the fenestron. The tailboom of helicopter Mil 8 is manufactured from aluminium alloy sheets, and it is assembled by traditional stringer/stiffener constructions. The crack detection here is successfully done using the attenuation of Lamb waves passing the crack area at hot spots. A major concern here was the durability of the attachment of the piezoceramic actuators and sensors during a complete fatigue life cycle, but that challenge that was successfully tackled [2].

2.3. The Tailboom of the Helicopter EC 135

It is manufactured from sandwich composite (CFRP). Here, SHM networks are focusing on barely visible impact damage. One option is to analyse the attenuation of guided waves, i.e. Lamb waves. In the focus of our research is the mode conversion from the so-called symmetric S0 into the anti-symmetric A0 mode [3].

2.4. Floor Structures

The floor in the cabin area of various types of aircraft is covered by floor panels that are mostly made from composites. These floor panels are mounted on the so-called floor beams. The floor beams are partially equipped with seat tracks, and beams and seat tracks are frequently made from aluminium alloys. When aqueous liquids are spilled, corrosion can occur that is able to heavily damage the aluminium alloy structure. Percolation sensors allow the detection of aqueous liquids and this is a simple way of avoiding corrosion at a very early stage (see later section in this contribution).

2.5. Double Repair

The repair of aluminium sheet structures that were damaged by e.g. an impact, is usually performed by doubler repair. Especially the outer rivet row is subjected to high stress loads that can lead to fast crack growth. A reliable SHM system detecting crack propagation between rivets would establish an interesting option. Hidden (subsurface) cracks are a major challenge in non-destructive testing. An interesting technology here is the application of flat coil sensors that are directly mounted in the primer coating. Reliable indication of crack growth is thus possible by monitoring the change of impedance (Pitropakis et al.).

3. Detecting Liquids by Percolation Sensors

In a wet surrounding it is always necessary to prevent corrosion. A typical example is the floor structure of an aircraft. The floor beams are protected by coatings, and the gaps between floor plates are equipped with dedicated sealing systems, such as silicone, isolating tapes and rubber mats. But during aircraft operations, coatings and sealings can be damaged which gives spilled liquids the possibility to cause corrosion. Another aspect is related to water that can enter sandwich composite panels. Famous hot-spots here are the galley and lavatory area. Penetration of liquids will thus cause heavy corrosion of floor beams and seat tracks. Unfortunately, the inspection of floor

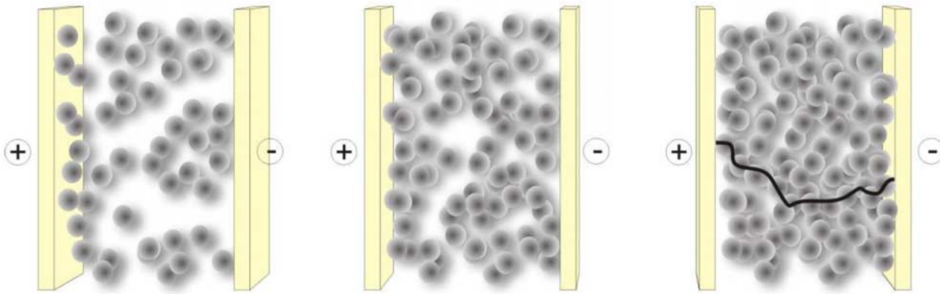


Figure 1. By percolation, conductive pathways are formed in a composite.

beams is performed only after relatively long time intervals (D-check 5–7 years), and so, a starting corrosion problem will remain undiscovered for a long time. Appropriate liquid sensors to be interrogated on e.g. a weekly basis could definitely help to avoid unnecessary maintenance and repair activities for floor structures. In this way, a reduction of the number of inspections is possible and is it possible to save costs for replacement of floor structure elements.

The sensor system reported here is based on the disappearance of percolation conductivity in electrically conducting hydrophilic composites. Those composites contain conducting particles that are embedded in a liquid-absorbing matrix. Percolation in this context means the interconnection of the conducting particles within the composite.

The principle of percolation conductivity is shown in (Fig. 1), here the embedded conducting particles are represented by spheres that are surrounded by the insulating matrix. When the volume fraction of the conducting particles is increased, the probability for an establishment of conducting pathways between the between the electrodes is also increasing. This is usually accompanied by a certain threshold, the so-called percolation threshold of conductivity. At his point, the material turns from an isolator into a conductor.

The variation of the electrical resistance at this percolation threshold can go beyond 16 orders of magnitude [4]. Because the percolation threshold depends strongly on the volume fraction, all physical quantities related to volume fractions would have a dramatic influence on resistance. Therefore, percolation sensors can provide interesting options for non destructive testing of leakage of liquids.

4. A percolation Sensor for Floor Structures

A specific organic-ceramic composite was developed to obtain an appropriate sensor for floor structures. Ceramic powders are normally not used in sensing applications. According to a recent literature research, no similar applications were reported, but here, they are interesting candidates. In most cases, conducting ceramic powders are applied for manufacturing of conducting ceramics. Those ceramics can be machined by spark erosion. In our case, the chemical stability of ceramic powders is most interesting, including fire and corrosion resistance. Metal powders in conducting polymers would be susceptible to corrosion when not using gold powder. As a liquid absorbing matrix material, polyvinyl alcohol (PVA) was selected. It is hygroscopic and it has a known swelling behaviour. Furthermore, its chemical compatibility is excellent. The volume

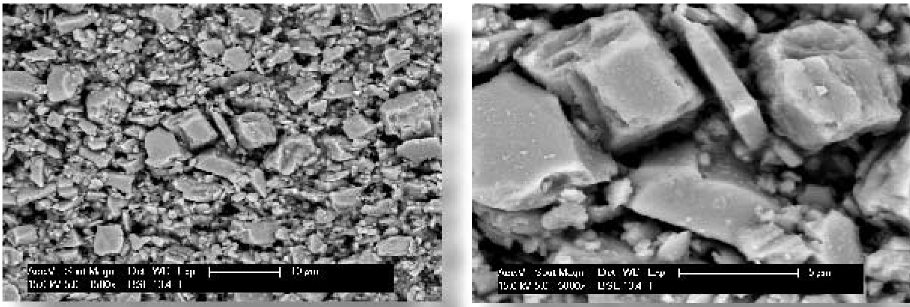


Figure 2. Details of the organic-ceramic composite revealed by Scanning Electron Microscopy (SEM).

fraction of the conducting components was selected so that the system is relatively far away from the percolation threshold. In this way, baseline variations (variations of humidity at normal operations) do not show a significant influence.

Advanced structural analysis was performed to study the microstructure of the hydrophilic composite. Scanning Electron Microscopy provided pictures of the conducting ceramic particles situated in the PVA matrix (Fig. 2). The conducting ceramic particles have an average size of a few micrometers.

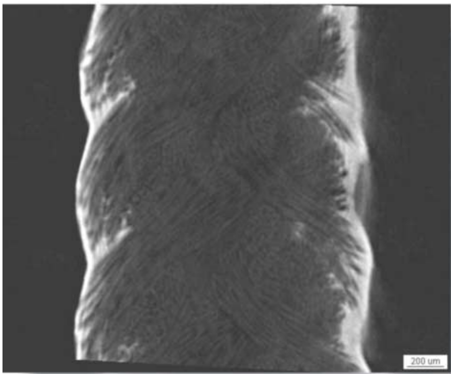
5. The Sensor and the Implementation in an Operational Airliner

When embedding sensors in floor structures, an important problem is established by the limited space available between floor panels. The width of the gap is in the range of one millimetre, and sharp bends challenge the bending performance of the sensor. Furthermore, the sensor needs to be extended with a length that reaches up to 3 m. The last property limits the "spatial resolution" of the sensor but for many applications, the exact location of spilled liquid is not really important to know. In a case of a liquid problem, sealings can be inspected for an extended area without any problems. Finally, large floor plate segments have to be removed anyway in case essential amounts of liquid have to be removed.

Aqueous dispersions of the organo-ceramic composite were prepared that were determined in previous test series. Finally, a nylon cord was equipped with a standard wire, i.e. it was mounted inside the core of the cord. After this, the surface of the nylon cord was impregnated with the aqueous dispersion of the organic-ceramic composite. During the drying process, the sensor became conductive. Sectional images of the interior of the sensor can be obtained by Microfocus X-ray imaging (μ-CT) (Fig. 3).

For testing the performance, the sensor was deposited in a tube that simulates conditions comparable to the gap between floor panels. The system was connected to a digital multimeter and software was developed for analyzing the readings. When e.g. 0.7 ml of a liquid spilled in an aircraft (cola in that case) was "spilled" on the sensor, a characteristic response was measured that is shown in Fig. 4.

The interactions between the components in the composite after contact with the liquid can be understood as follows, when the liquid enters the composite the local concentration of water increases until the percolation point is reached, the sharp steep in resistance (Fig. 4) thus represents a time-depending, diffusion-driven percolation



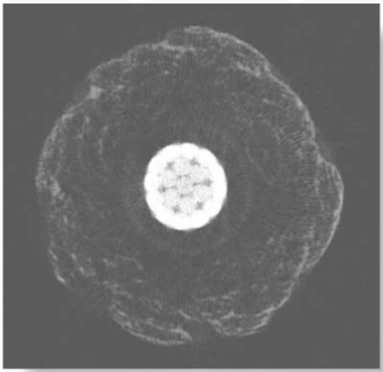


Figure 3. μ-CT picture (microfocus X-ray imaging) of the sensor, the diameter is approximately 1 mm. Left picture: The white pixels at the surface of the nylon cord present the conducting ceramic powder. Right picture: The white dots indicate the Cu wire in the core of the nylon cord.

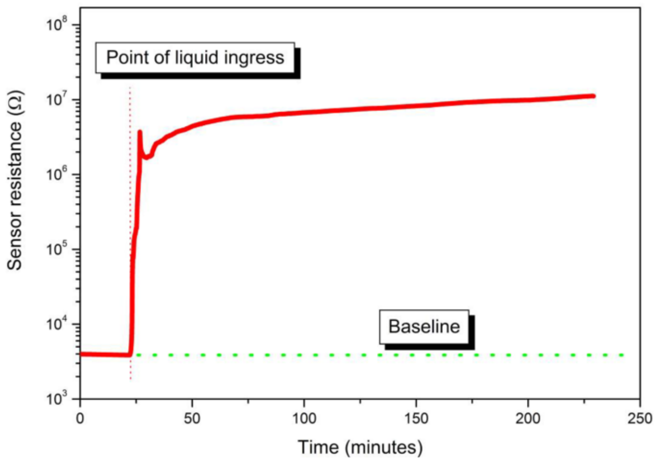


Figure 4. Recorded signal after water ingress.

threshold. The liquid finally came in contact with the sensor over a length of about 5 cm. The liquid itself is also modestly conductive (usually, those liquids are electrolytes). But it is clear from Fig. 4 that the remaining conductivity is essentially lower than the initial conductivity in the composite at dry conditions. Another interesting performance of the sensor is related to its buffer capability, i.e. absorbed spilled water is no longer available for corrosion.

For the present case, the resistance has increased by a factor of about 5000. This exceeds the baseline variations by many orders of magnitude. In this way, the sensor gives a good answer to the challenge related to many SHM sensor concepts, i.e. the problem to distinguish between baseline variations and damage-related signals.

The current sensor system keeps its state for a sufficiently long time due to the limited space where the sensor is deposited and due to the hydrophilic nature of the matrix material itself. In this sense; the sensor represents a kind of a fuse. This is definite-

Figure 5. Boeing 737-500 Left picture: The extended sensor (black wire) is deposited in the gap between floor panels. Right picture: Partially re-sealed floor in the galley area.

ly a major advantage because there is no need to implement additional electronics into the airplane. This also helps reducing certification efforts. For the daily practice, it has been proven to be sufficient to measure the resistance in time intervals of several days using a low-end multimeter. In a later stage a data connection to the ARINC bus of the airplane could be established and information on wet floor structures would be directly fed into the maintenance computer present in many airplanes.

In the meanwhile, the sensor was implemented in an operational airliner after all required certification steps were followed. As hot-spots, the galley and the lavatory area as well as the space below the doorstep of the galley door were selected (Fig. 5). The implementation was done on a Boeing 737-500 (at the moment of implementation it had app. 40000 flight hours) from Lufthansa during the D-check. The total length for all sensors is 4 m. Reading out of the resistance data is performed in time intervals of about 100 flight hours. Data are now collected and analyzed. First results were obtained that give more insight in the microclimate present in the gaps between composite floor plates and those result might already be the reason for the improvement for maintenance procedures.

Finally, the concept of a percolation sensor was extended to different liquids frequently used in an aircraft. An important application is e.g. the detection of hydraulic liquid (SKYDROL® to be used for hydraulic tubes), or mineral oils (e.g. to be applied in jet engines) and kerosene. For all those liquids, appropriate sensors were developed and implementation is partially under preparation.

Acknowledgement

The research leading to these results has received funding from the European Community's Seventh Framework Programme [FP 7/2007-2013] under grant agreement n°212912 (Project: Aircraft Integrated Structural Health Assessment II – AISHA II).

We want to thank Gregory Pyka for performing the SEM analysis and Johan Vanhulst for establishing the data logging facilities. Furthermore, a special thank to Kim Vanmeensel and Wout Veulemans for the support with the ceramic powder technology.

References

[1] H. Pfeiffer, D. De Baere, F. Fransens, G. Van der Linden and M. Wevers, "Structural Health Monitoring of Slat tracks using transient ultrasonic waves", in EU Project Meeting on Aircraft Integrated Structural Health Assessment (AISHA), Vol. 13 (10), 2008, www.ndt.net, Leuven, Belgium.

[2] S. Kuznesov, E. Ozolinsh, I. Ozolinch, I. Pavelko, H. Pfeiiffer and M. Wevers, "Some results of Ultrasonic Detection of Uniform Corrosion in thin AI2024-T3 Sheets", in EU Project Meeting on Aircraft Integrated Structural Health Assessment (AISHA), Vol. 13 (10), www.ndt.net, Leuven, Belgium.

[3] W. Hillger and A. Szewieczek, "Impact Detection in a Composite Tail Boom Structure with Ultrasonic Imaging and Guided Waves Techniques", in Proceedings 10th European Conference on Non-Destructive Testing, Moscow, 2010, June 7–11, http://www.ndt.net/2010.

[4] M. Kupke, H.P. Wentzel and K. Sculte, "Electrically conductive glass fibre reinforced epoxy resin", Materials Research Innovations, Vol. 2, 1998, pp. 164–169.

About the Authors

Dr. Helge Pfeiffer, Project Manager at KU Leuven
Prof. Dr. MartineWevers, Lecturer at KU Leuven
Katholieke Universiteit Leuven
Department of Metallurgy and Materials Engineering (MTM)
Kasteelpark Arenberg 44 Bus 2450
3001 Leuven, Belgium
Tel.: 0032/16/32 12 32, 0032/16/32 13 03
helge.pfeiffer@mtm.kuleuven.be
martine.wevers@mtm.kuleuven.be
www.aisha2.eu

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-315

MAAXIMUS – Delivering Innovation

Jocelyn GAUDIN and Ralf HERRMANN

Abstract. Even though composite materials are more and more used in modern airframes, many significant improvements are still achievable. The substitution of the assembly of many small composite parts by one-shot larger part may provide additional weight and recurring cost reduction by removing rivets and holes. Secondly, the final assembly line process must be adapted to composite properties (lack of ductility, stiffness) in order to secure a high assembly rate of composite sections and ensure a high production rate. At last, if the appropriate level of confidence and cycle time was available, Simulation-based design would provide a faster and less expensive path to find the optimal structures than the current development process, which relies on intensive physical test campaigns. MAAXIMUS was set up to explore composite solutions that go beyond traditional black metal approach.

Keywords. Composite materials, airframes, optimal structures, right-first-time structure

1. Project Description

The aim of MAAXIMUS (More Affordable Aircraft structure through eXtended, Integrated, & Mature nUmerical Sizing) is to demonstrate the fast development and right-first-time validation of a highly-optimised composite airframe. This will be achieved through coordinated developments on:

- A physical platform, to develop and validate the appropriate composite technologies for low weight aircraft;
- A virtual structure development platform, to identify faster and validate earlier the best solutions.

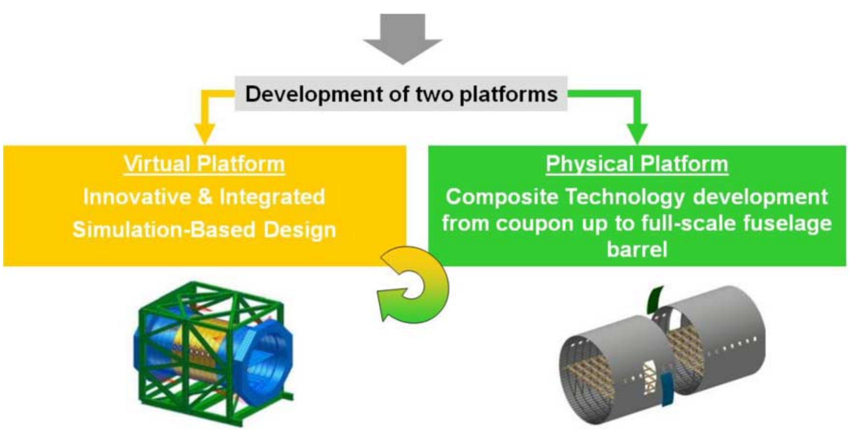


Figure 1. Fast Development & Right-First Time Validation of a highly-optimized New Generation Composite Fuselage by a Simulation-based design.

The dual approach of simultaneously working on virtual and physical enablers is absolutely necessary to develop both platforms with their specific and dependent needs, and to cross-validate their respective achievements. This project constitutes a unique chance to demonstrate the efficiency of virtual structure development in the context of a real innovative composite airframe structure development. This approach is expected to introduce a “cultural change” in the way airframes will be developed in Europe.

It will enable for the airlines, aircraft with lower acquisition and operating costs, a reduced Time-to-Market and a reduced environmental impact. MAAXIMUS strongly contributes to strengthen the European aeronautical industry.

The MAAXIMUS objectives related to the highly-optimised composite airframe are:

- To enable a high-production rate with 50% reduction of the assembly time of large composite sections by an increased use of robotics for assembly automation and tolerance management and to demonstrate this achievement through the assembly of two composite sub-components representative enough of composite fuselage final assembly context;
- Reduce the manufacturing and assembly recurring costs by 10% compared to the ALCAS equivalent reference, as a result of more integrated structures;
- Reduce the structural weight by 10%. Acoustics, lightning strikes, thermal effects, production ramp-up and rate, increased maintenance interval will be considered together with weight.

The MAAXIMUS objective related to a faster development is to:

- Reduce by 20% the current development timeframe of aircraft structures from preliminary design up to full-scale test (ALCAS reference), and by 10% the corresponding non-recurring cost, by a much higher integration of structure disciplines, with a higher fidelity and confidence in the virtual assessment of structural behaviour during the numerical optimisation process.

The MAAXIMUS objectives related to the right-first-time structure are to:

- Additionally reduce the airframe development costs by 5% compared with the equivalent development steps in an industrial context (number and description of tests performed, man-hours for design, sizing and manufacturing), through the delivery of a predictive virtual test capability for large composite structures up to failure with a quantified level of confidence. This capability will be assessed and validated through an exhaustive comparison with a pre-existing full-scale physical test of a composite fuselage barrel. A new Certification Philosophy, based on Virtual Testing, will be also assessed. It will also consider the structure as it is actually manufactured and assembled and not only as it is designed;
- Avoid late and costly changes due to unexpected test results. Virtual Testing will be a major asset to freeze a trouble–free design earlier than today. It will provide more mature aircraft to the customers at Entry Into Service, with fewer Service Bulletins or post-entry into service modifications. This will be a key asset for airliner satisfaction.

The Consortium of 57 partners from 18 countries is made up of aircraft manufacturers, material behaviour specialists, software developers, computational mechanics experts and test centres, both from industry and Academia institutions. The combina-

Figure 2. The MAAXIMUS map: 57 partners from 18 countries.

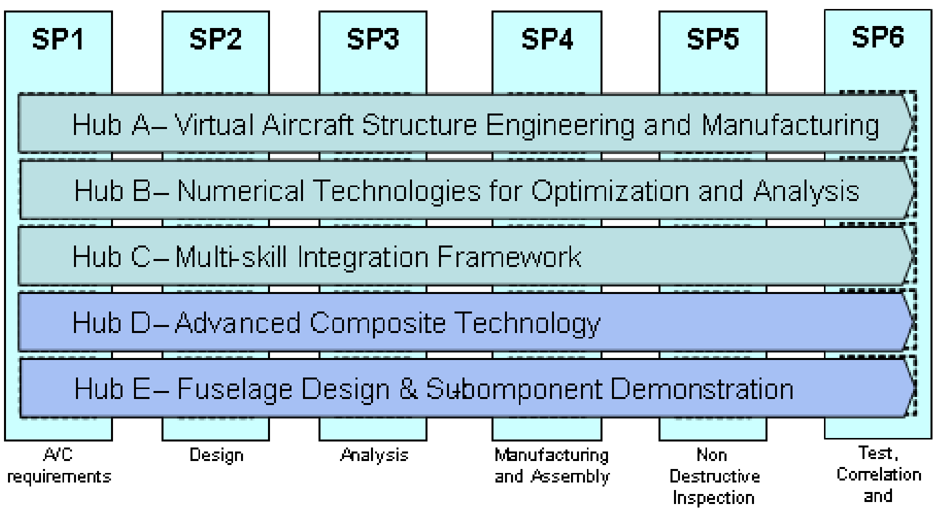


Figure 3. 'Multi-skill integration framework' theme into Sub-projects.

tion of such experience and know-how ensures proper capitalisation of results from past and current national and international projects.

The project is organized in a kind of matrix with 5 thematic hubs as they are *Virtual Aircraft Structure Engineering and Manufacturing, Numerical Technologies for Optimisation and Analysis, Multi-skill Integration Framework, Advanced Composite Technology* and *Fuselage Design & Sub component Demonstration* on one hand and 6 Sub-Projects for cross-thematic skills like *Project Management, Aircraft Requirements, Design, Analysis, Manufacturing & Assembly, Non-Destructive Investigation*, and *Test & Correlation* on the other hand.

2. Project Achievements

Several milestones have now been reached:

- Composite Fuselage operational requirements and relevant metrics are completed;
- Virtual Development Challenges, Virtual testing certification requirements and metrics are completed;
- Preliminary Barrel Design, including the detailed lay-up design performed and limitations identified;
- The advanced Panel Concept has been delivered;
- Requirements and specifications for the MultiSkill Integration Framework, including NDI, HPC and Test disciplines has progressed;
- The Reference Model for the barrel Gigadof challenge is available and operationally used by partners;
- Design of coupons/details/panels is finalized;
- Materials and processes are selected.

The relatively low loads in fuselages for business jets and small commercial aircrafts and current design principles may lead to very thin composite structures. Such thin composite skins and stiffeners may be much more prone to manufacturing defects and robustness issues than metallic ones. Also the composite recurring cost is also higher with the foreseen design principles than for metallic solutions.

This is valid for both small commercial aircrafts and business aircraft.

The current status versus the MAAXIMUS target is like this:

- –10% Weight;
- –10% Manufacturing and assembly recurring cost;
- –50% Section Final Assembly Line time;
- –20% Development time;
- –15% Development cost.

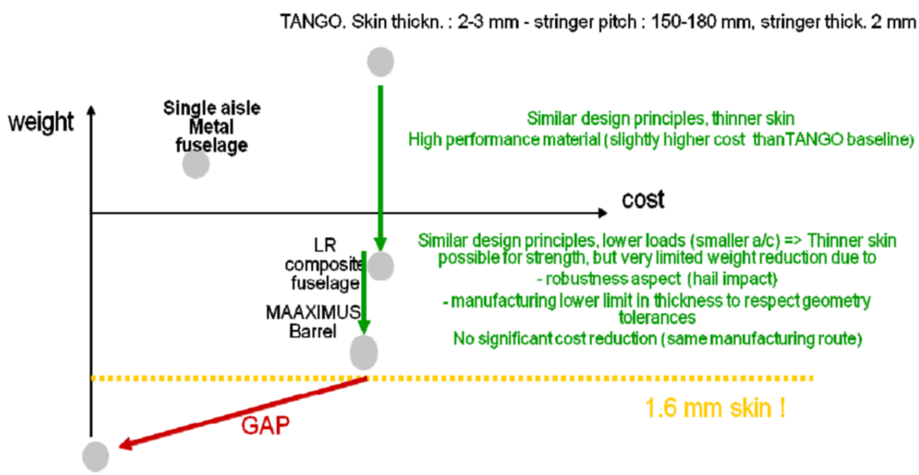


Figure 4. Current status versus target.

This means that more innovation would needed to reach the MAAXIMUS target. The next steps will be to validate the advanced damage and failure models at material level and panel level, to further explore more innovative design solutions and architectures to find better weigh-cost solutions and to secure High-Performance Computing capabilities and integrate them into an industrial framework.

Finally the benefits of MAAXIMUS innovation have to be demonstrated at full-scale level.

3. Conclusion

The main expected impact from MAAXIMUS is the higher competitiveness of the European aircraft industry, obtained by a reduced time-to-market of better (lighter and trouble-free) aircraft. Since the airframe manufacturers represented in MAAXIMUS are world actors of business jet, regional and commercial aircraft industry this ensures that the benefits from MAAXIMUS research and technological developments will be easily available for the airframe industry, with lower transfer time or industrial bottlenecks.

The positive impact on the competitiveness of the European aircraft industry will be turned into direct positive employment impact by securing the overall sector situation. The project will also especially secure high-education employment, with a major effort in the virtual development capabilities (information technology, computational mechanics, and mathematics) on top of airframe related skills. This will help to develop careers with attractive high-tech content and will help to strengthen the quality of future jobs in the aircraft industry.

MAAXIMUS is a key enabler of Fast Development of Right First Time innovative aircraft:

- Major step in design robustness and predictive capabilities;
- Leap forward in the aircraft structure optimisation foundations;
- Integrated CAD-CAM-CAE framework for aircraft Development;
- Targeting demonstration on a full-scale composite fuselage section.

About the Authors

Jocelyn Gaudin
MAAXIMUS Project Coordinator
Airbus Operations SAS
316, route de Bayonne – BP M0121/3
F- 31060 Toulouse Cedex 9
jocelyn.gaudin@airbus.com

Ralf Herrmann
MAAXIMUS Project Coordinator
Airbus Operations GmbH
Airbus-Allee 1
D-28199 Bremen
Ralf.Herrmann@airbus.com

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-320

Improved Material Exploitation of Composite Airframe Structures by Accurate Simulation of Collapse

The "COCOMAT" Project

Richard DEGENHARDT

Abstract. European aircraft industry demands for reduced development and operating costs, by 20% and 50% in the short and long term, respectively. Supported by the European Commission, the research project called "COCOMAT" which started in January 2004 and finished in 2008 contributed to this aim. The objective was to allow for a structural weight reduction by exploiting considerable reserves in primary fibre composite fuselage structures through an accurate and reliable simulation of post-buckling and collapse. This paper, after having recalled the detailed objectives of the project, gives an overview about the major results obtained.

Keywords. Composite airframe structures, safe design, collapse, accurate simulation, adaptive systems

1. Introduction

COCOMAT, which started in January 2004 and was finished October 2008, contributed significantly to reduced development and operating costs. COCOMAT stands for Improved MATerial Exploitation at Safe Design of COmposite Airframe Structures by Accurate Simulation of Collapse. The project was co-ordinated by DLR, Institute of Composite Structures and Adaptive Systems. It aims at allowing for a structural weight reduction by exploiting considerable reserves in primary fibre composite fuselage structures through an accurate and reliable simulation of postbuckling and collapse [1,2].

The COCOMAT project builds up on the results of the FP5 POSICOSS project which is the acronym of Improved Postbuckling SImulation for Design of Fibre COmposite Stiffened Fuselage Structures. POSICOSS developed improved, fast procedures for postbuckling analysis of fibre composite stiffened panels, created experimental data bases and derived design guidelines [3,4].

The COCOMAT project extends the POSICOSS results and goes beyond by a simulation of collapse. That requires knowing about degradation due to static as well as low cycle loading in the postbuckling range. It is well-known that thin-walled structures made of carbon fibre reinforced plastics are able to tolerate repeated buckling without any change in their buckling behaviour. However, it had to be found out, how deep into the postbuckling regime the loading can be extended without severely damaging the structure, and how the behaviour can be predicted by fast and precise simulation procedures. This issue was dealt with by COCOMAT. COCOMAT improved

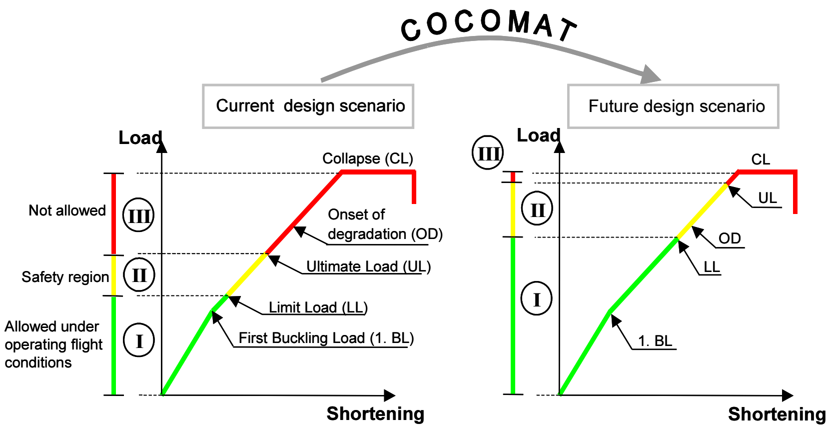


Figure 1. Current and future design scenarios for typical stringer stiffened composite panels [4].

existing slow and fast simulation tools, created experimental data bases and set up design guidelines for stiffened panels taking skin stringer separation and material degradation into account.

The consortium merges knowledge from industrial partners (AGUSTA-Westland, AERNNOVA, HAI, IAI and PZL), 2 Small and Medium Enterprises (SAMTECH and SMR), 3 research establishments (DLR, FOI and CRC-ACS) and 5 universities (Politecnico di Milano, RWTH Aachen and University of Karlsruhe, TECHNION and Technical University of Riga).

2. Objectives and Results

COCOMAT mainly strives for accomplishing the large step from the current to a future design scenario of typical stringer stiffened composite panels. Figure 1 demonstrates the aspired achievements by means of a simplified load-shortening curve including buckling, postbuckling behaviour and collapse. The left graph illustrates the current industrial design scenario.

Three different regions can be specified. Region I covers loads allowed under operating flight conditions and is bounded by Limit Load (LL); region II is the safety region and extends up to Ultimate Load (UL); region III comprises the not allowed area which reaches up to Collapse. In aircraft design Ultimate Load amounts to 150% of Limit Load. There is still a large unexploited structural reserve capacity between the current Ultimate Load and Collapse. The right graph of Fig. 1 depicts the design scenario aspired in future, where Ultimate Load is shifted towards Collapse as close as possible. Through that move the onset of degradation appears no longer in the not allowed region III but already in the safety region II. This is comparable to metallic structures where plasticity is permitted in the safety region. However, it must be guaranteed that in any case the onset of degradation must not occur below Limit Load. Moreover, the extension requires an accurate and reliable simulation of Collapse, which means to take into account degradation under static as well as under low cycle loading to assure its limited progression.

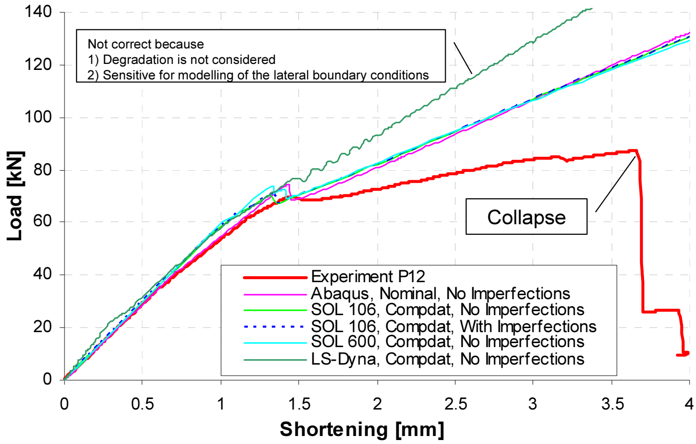


Figure 2. Selected results on benchmarking [6].

The project results comprise a data base on material properties and on collapse of undamaged and pre-damaged statically and cyclically loaded structures, degradation models, improved slow and fast computation tools for statically loaded structures as well as design guidelines, which take skin stringer separation and material degradation into account. The experimental data base was indispensable for validation of the analytically developed degradation models, which were implemented into the new tools and for verification of the computed results as well.

3. Selected Results

This section shows an overview about some main results. A list of papers already published by the partners can be found at www.cocomat.de.

3.1. Benchmarking

The partners selected two panel tests from the POSICOSS project as benchmarks on undamaged structures. In order to obtain test results of a comparable pre-damaged panel one panel from the POSICOSS project was refurbished, a minor damage was fixed, and then the panel was pre-damaged by IAI and tested by TECHNION. In addition, the consortium exchanged test results of pre-damaged benchmark structures with Airbus Germany. The partners applied different finite element tools on the benchmarks in order to simulate the structural behaviour up to collapse. They identified abilities and deficiencies of simulating the degradation. Some detailed results on the two undamaged benchmarks were published in [5]. As an example Fig. 2 shows the load shortening curve of an undamaged axially loaded CFRP panel provided by DLR and the comparison with simulations by means of the commercial tools ABAQUS and NASTRAN.

There is a good agreement of all curves from the pre-buckling region up to the first global buckling (at 1.4 mm shortening) where the stringers buckle. From that point on there is still a good agreement between most of the numerical simulations. However,

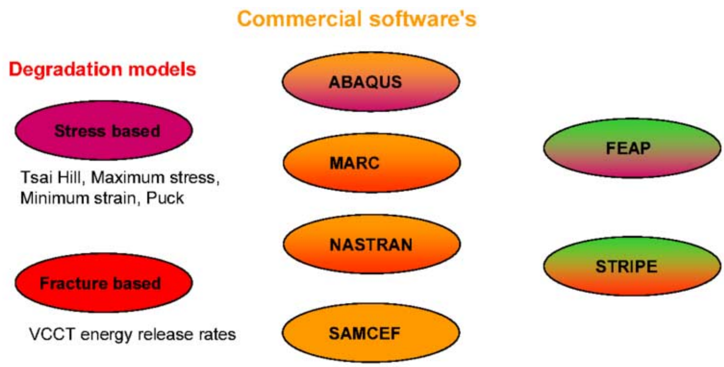


Figure 3. Family of slow certification computational tools.

they deviate from the experimental results which is not unexpected because the numerical simulation did not take degradation (e.g. material degradation, skin-stringer separation or the delamination in the stiffener blade) into account. This demonstrated the needs for improving the simulation tools to include the effect of the most important types of degradation. In addition, the lateral boundary conditions largely influence the results in the far postbuckling region. Consequently, the boundary conditions must be modelled with great care. More details can be found in [6].

3.2. Improvement of Computational Tools

This main workpackage deals with the improvement of slow and fast computational tools, which take degradation into account. Very accurate but necessarily slow tools are required for the final certification, whereas reliable fast tools reducing design and analysis time by an order of magnitude, will allow for an economic design process. Finally, all tools are validated by means of the experimental results obtained from the other workpackages.

The first task concentrates on the improvement of slow simulation tools. The partners adopted different approaches. Figure 3 gives an overview about the slow certification tools considered and approaches for modelling the degradation. For simulating the skin-stringer separation of composite structures DLR developed an ABAQUS user subroutine and applied it to calculate the structural behaviour of panels up to collapse [5]. The second task concentrates on the improvement of design procedures for the fast simulation of collapse behaviour of stringer stiffened fibre composite panels. The tools are faster at least by a factor of 10 than respective Finite Element (FE) simulations at accuracy, which is sufficient for design purposes.

A diagram representing overall precision and computing time of fast simulation procedures with degradation developed by the different partners is presented in Fig. 4.

DLR considered the iBUCK which was developed in a previous project. iBUCK is a tool for the fast simulation of the postbuckling behaviour of aerospace structures [7]. The model is based on the Donnell type shell equations for thin, slightly curved shells that undergo large deflections. Stringers are considered as structural elements with independent degrees of freedom and are not “smeared” onto the skin. Continuity in terms of rotation at the interface skin/stiffeners and in terms of end-shortening is enforced. Local and global buckling modes are superposed, where local buckling is defined as

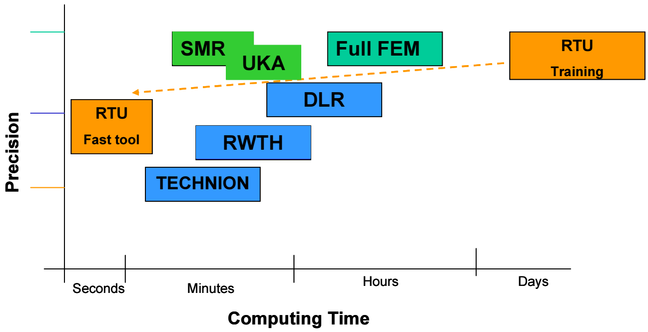


Figure 4. Family of fast design computational tools.

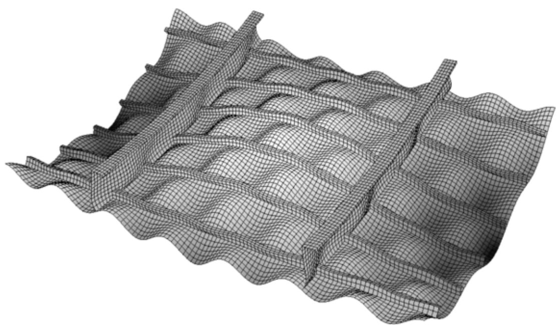


Figure 5. Postbuckling shape obtained by iBUCK [7].

skin buckling and skin-induced stiffener rotation within a bay. During local buckling, the stiffeners themselves are not allowed to deflect in out-of-plane direction. During global buckling, that is, buckling across several bays, the stringers may deflect in out-of-plane direction, whereas the frames, being much heavier than the stringers, are fixed in out-of-plane direction. The panel may be loaded axially and bi-axially. In addition, one load case that is of special interest for the aircraft industry is included: the loading by an external bending moment in circumferential direction which may act in an opening or closing mode. All external loads may be applied individually or in combination. In COCOMAT iBUCK was further developed to include composite materials and skin-stringer separation. Figure 5 illustrates one postbuckling shape obtained by iBUCK.

3.3. Panel Tests

The main objective of the panel testing is the extension of the experimental data base on collapse of undamaged and pre-damaged stringer stiffened composite panels under static and low cycle loading. 19 undamaged and 24 pre-damaged panels were tested under different load cases (e.g. compression or shear) or load scenarios. The panels are grouped into 6 different designs which were selected from a design pool of over 70 panels designed at the beginning of the project. The design process for the panels designed by DLR is described in detail in [6]. To study the degradation process experimentally some panels were tested cyclically by several thousands cycles until a certain

level (e.g. 70–95% of the expected collapse load) and finally until collapse. Cyclic loading is understood here as repeated static loading. To measure the degradation process (e.g. skin-stringer separation) already during the tests advanced measurement systems as thermography, ARAMIS and lamb waves are used. Details to the asurement systems used by DLR for selected panel tests were published in [8].

3.4. Design Guidelines

All project results were summarised in design guidelines [9]. The analysis guidelines cover FE types and meshing, damage mechanisms, degradation models, recommendations regarding interface elements in the damage zone and ply failure models. Comparison between various analysis codes is also provided.

Lessons learned concerning testing of structures in the buckling regime were concluded. The sensitivity of conventional design to damage of various sizes has been investigated, and conclusions are drawn regarding design criteria. Israel Aerospace Industries (IAI) selected two structural applications for industrial validation, where the above-mentioned guidelines were successfully applied.

4. Summary

The main objective of the finished COCOMAT project is the future design scenario for stringer stiffened CFRP panels (Fig. 1). COCOMAT considers simulation of collapse by taking degradation into account. The results comprise an extended experimental data base, degradation models, and improved certification and design tools as well as design guidelines. The project demonstrated successfully that the postbuckling region can be further exploited for the industrial design applications. This paper deals with the main objectives and gives an overview about the main results of the project COCOMAT. A list of published papers by the partners can be found at www.cocomat.de.

References

[1] R. Degenhardt, R. Rolfes, R. Zimmermann and K. Rohwer, “COCOMAT – Improved MATerial exploitation at safe design of COmposite airframe structures by accurate simulation of COllapse”, Composite Structures, Vol. 73 (2006), pp. 175–17.

[2] www.cocomat.de.

[3] R. Zimmermann and R. Rolfes, “POSICOSS – Improved postbuckling simulation for design of fibre composite stiffened fuselage structures”, Composite Structures, Vol. 73 (2006), pp. 171–174.

[4] www.posicoss.de.

[5] A.C. Orifici, R.S. Thomson, A.J. Gunnion, R. Degenhardt, H. Abramovich and J. Bayandor, “Benchmark finite element simulations of postbuckling composite stiffened panels”, 11th Australian International Aerospace Congress, Melbourne, Australia, 13–17 March, 2005.

[6] R. Degenhardt, A. Kling, K. Rohwer, A.C. Orifici and R.S. Thomson, “Design and Analysis of Stiffened Composite Panels Including Postbuckling and Collapse”, Computers and Structures (paper in print, 2007, doi:10.1016/j.compstruc.2007.04.022).

[7] P. Bürmann, R. Rolfes, J. Tessmer and M. Schagerl, “A semi-analytical model for local postbuckling analysis of stringer- and frame-stiffened cylindrical panels”, Thin-Walled Structures, Vol. 44 (2006), pp. 102–114.

[8] R. Degenhardt, A. Kling, H. Klein, W. Hillger, Ch. Goetting, R. Zimmermann, K. Rohwer and A. Gleiter, “Experiments on Buckling and Postbuckling of Thin-Walled CFRP Structures using Advanced Measurement Systems”, International Journal of Structural Stability and Dynamics, Vol. 7, No. 2 (2007), pp. 337–358.
[9] G. Ghilai, E. Feldman and A. David, “COCOMAT Design and Analysis Guidelines for CFRP-Stiffened Panels in Buckling and Postbuckling”, International Journal of Structural Stability and Dynamics, Vol. 10, No. 4 (2010), pp. 917–926.

About the Author

Richard Degenhardt
DLR – Institute of Composite Structures and Adaptive Systems
Lilienplatz 7
D-38108 Braunschweig, Germany
Richard.degenhardt@dlr.de
www.dlr.de

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-327

DOTNAC – Development and Optimization of THz NDT on Aeronautics Composite Multi-Layered Structures

Marijke VANDEWAL

Abstract. Modern aircraft structures have to comply with severe requirements: they have to be light as well as safe. These requirements lead to an increased use of composite materials in the aircraft industry. However, new materials also require new techniques in order to inspect aircraft components during production in a non-destructive way. The European research programme "DOTNAC" proposes to develop a fast, high resolution, non-invasive and non-contact inspection system for assessing aeronautic composite parts during production. The THz spectrum covers a frequency spectrum from the far to the mid-IR.

Keywords. Terahertz (THz) detection, non-destructive testing, non-invasive composite inspection, non-contact composite inspection

1. Introduction

Composite materials containing aramid fibres, glass fibres, carbon fibres, poly-urethane foam, and others, used in specific structures such as honeycomb and sandwich structures, are recognized for their high strength to weight ratios, and have found use as structural components in demanding applications such as aircrafts. Despite these advantages they have vulnerabilities that are most exposed during the manufacturing and maintenance phases. During manufacturing, problems may occur during the layer build-up stage when foreign object debris (FOD) parts of metal, plastic, backing material and/or other parts of fabrication-related debris can become embedded within the layers of uncured composite material. Such and other defects de-crease the integrity of layer adhesion and overall strength of a composite component leading to high rejection rates. To support the high standards of composite part construction and repair, new non-destructive techniques are necessary to improve the efficacy of composite part inspection, when existing techniques fail to. To meet this need, DOTNAC is developing a non-invasive, non-contact inspection system for assessing composite part condition.

2. Added Value of a THz NDT Tool

Over the past several years, there has been a significant interest in the potential of terahertz (THz) detection for imaging of concealed weapons, explosives and chemical and biological agents. There are two major factors contributing to this interest: (1) Terahertz radiation is readily transmitted through most non-metallic and non-polarized me-

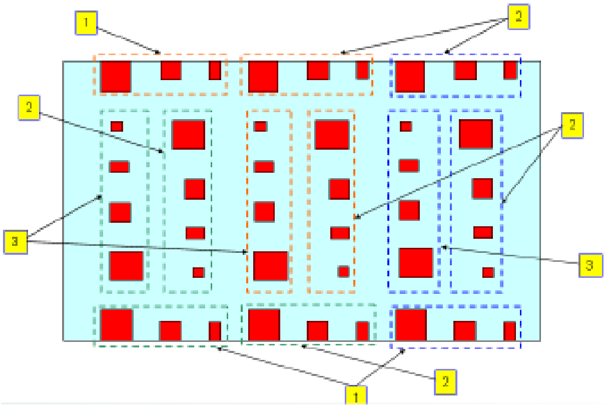


Figure 1. Example of a calibration object to be tested with the THz NDT tool as well as the established NDT tools such as RT, UT, and IRT. In the above figure the material can be fiberglass or quartz laminates, or sandwich structures. The red areas represent different types and sizes of inclusions.

dia, thus enabling THz systems to 'see-through' materials, (2) THz radiation is non-ionizing and poses no health risk to the system's operator. By taking advantage of these unique radiation properties, THz imaging can be used for NDT purposes: FOD and other defects such as delaminations, voids and heat damage can be identified in a variety of pre-cured and in-service composite structures.

As optical techniques have been deployed widely for surface inspection and superficial flaws and faults detection, time has come for THz systems to be customized to look deep into the aeronautical structure. Since the use of X-ray includes strict handling procedures, due to its danger to human exposure, and ultrasound NDT can lack precision, the possibility to detect deep into the structure is being advertised by THz remote sensing. THz measurement techniques can therefore be important for NDT as a completing solution to others.

Nowadays not much research is being performed and hence very few publications exist on THz imaging in air transport NDT, and little is known on how typical composite material defects such as delamination, porosities and inclusions can be de-tected by THz waves.

3. Objectives

The main goal of the DOTNAC project is to de-velop a fast, high resolution, non-invasive and non-contact inspection system for assessing aeronautic composite parts during production. The developed NDT tool will be easy to integrate in industrial facilities and will fill in the performance gaps that are still present amongst the existing NDT tech-niques; it will therefore be an extremely useful tool in NDT in terms of sensor fusion. Indeed, as often in the domain of NDT, this new method will not replace directly the existing NDT tools, but will deliver complementary results which can be some-times more precise for some defects (like delamina-tion or water ingress).

To achieve this overall goal, several underlying objectives will be set and consequently achieved: the assessment of aeronautic relevant composite materials and occurring defects (Fig. 1), the creation of two fast, non-mechanical THz imaging systems

Figure 2. For the demonstration of the proof of concept at the end of the project, a radome-like object as shown in this figure will be tested in-situ with the developed THz NDT tool.

(one using pulsed signals and optical fibre coupling, the other one continuous wave signals and electrical cable coupling), the building of a 3D scanning system enabling the THz imaging systems with associated command, control and data processing software, the final integration of the two THz systems (separately) and the 3D scanner will allow the DOTNAC project maximum liberty of movement to scan the object under inspection (Fig. 2), and the according optimization of 2 complementary signal processing and imaging software.

To finally achieve the main goal, the above developed hard- and software will be integrated and optimized, the THz NDT tool will be used to image the initially defined composite materials and structures, and the results will be compared with well-developed NDT systems. Finally, a global assessment of the THz system performances with respect to the composite materials and defects relevant in air transport will be performed.

4. Non Destructive Testing

A high-performance NDT tool should combine a number of characteristics such as resolution, penetration depth, flexible measurement set-up (trans-mission and reflexion measurements) and easy industrial integration. Additionally an NDT tool should be preferably contact-free and safe. Established non-destructive methods for the quality inspection and control of composite materials are ultrasonic testing (UT), radiographic testing (RT), millimetre wave (MMW) imaging and infrared thermography (IRT). Regarding actual NDT capabilities, there is a need of innovative systems. The main requested improvements are the following ones:

- Sensor resolution increase: defects are currently considered during parts calculations, through specific margins. So, if the resolution is improved (coupled with good results regarding critical defect size characterization, through mechanical studies), one can assume to generate weight saving;

Table 1. The principal characteristics of the main NDT methods used in aeronautical materials and components (limited to non-metallic materials and sub-surface and/or in-depth defects

Test type	Applied to non-metallic materials	Defect types	Application time	Observations
X-Rays	Very good	Superficial and internal	Slow	Requires installation and special handling
Ultrasound	Very good	Superficial and internal	Slow / Medium	Requires installation and specific techniques
IRT	Very good	Superficial and sub superficial	Medium/Fast	Requires installation and specific techniques (cheaper than ultrasound)

- Measurement speed improvement: the measurement of large parts requires a lot of time. A significant improvement of control speed is very interesting for industry (for cost saving and capability increase);
- Integration improvement: systems such as RT and UT water jet systems are very complicated to integrate into facilities and require complex maintenance. New systems have to be cheaper in terms of investments costs (acquisition, maintenance and facility integration) and should have advanced on site capacities.

Table 1 [1] shows the principal characteristics of the main NDT methods used in aeronautical materials and components (limited to non-metallic materials and sub-surface and/or in-depth defects).

5. THz Systems

Terahertz (THz) wave radiation is defined as the far-infrared (FIR) electromagnetic radiation between 0.1 and 10 THz (1 THz = 1012 Hz) as shown in Fig. 3. Inefficient generation techniques and high atmospheric absorption constrained early interest and funding for THz science.

Over the last decade, the THz domain has been opened up, and it has become a rich field for fundamental physics and technological application. Two main approaches exist: pulsed and continuous-wave (CW) THz systems and both can be used as a sensing or imaging tool. This project will use a pulsed THz system also referred to as a time do-main (TD) system [2], as well as a frequency modulated continuous wave system (FMCW).

In recent years, THz wave pulsed systems and applications have been oriented to spectroscopy and imaging. The generated pulses are either reflected or transmitted through a sample (both transmission and reflection mode are possible) and detected in amplitude and phase. Typical experiments aim at measuring absorption, refractive index or conductivity of a sample at THz frequencies [3]. Further intriguing possibilities lay in the three-dimensional visualization of echoes of THz pulses from internal interfaces enlightening the internal structure of a sample.

Frequency-modulated continuous-wave (FMCW) techniques are ideal when available transmitter power is limited and high detector sensitivity is needed [4]. For the signal generation a transmitter uses a chirped signal centered at a certain frequency. Up till now FMCW up to 100 GHz is quite standard, but only a few papers are known at

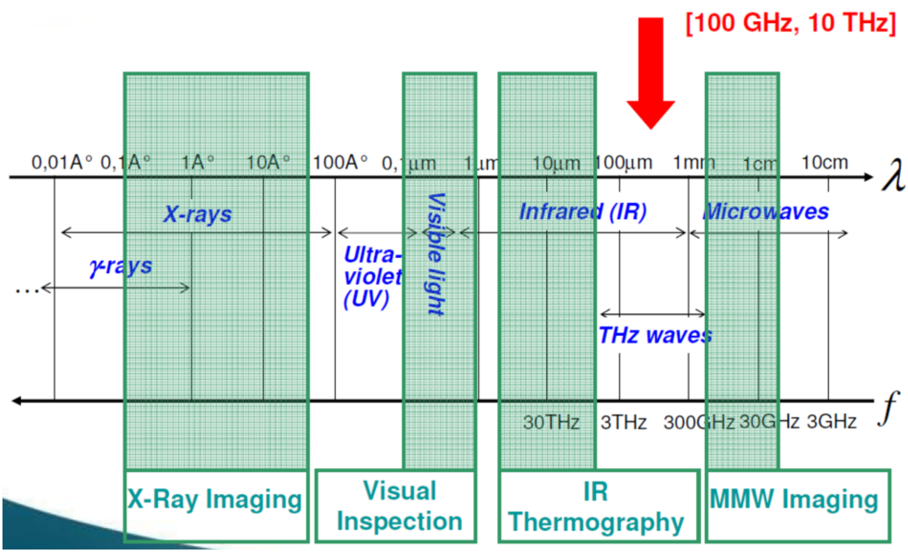


Figure 3. Definitions of the THz spectral band and comparison with the spectral band of RT, IRT, MMW and visual inspection.

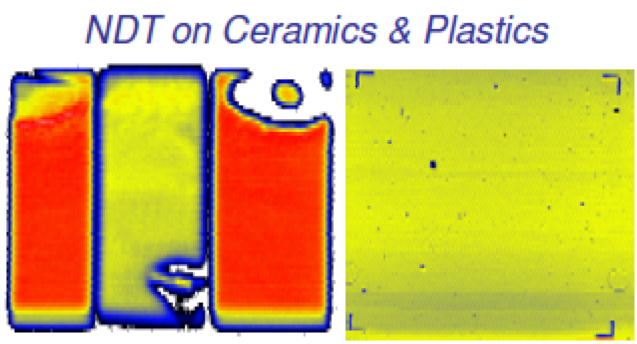


Figure 4. Transmission images for detection of porosity within ceramic (left) and of inhomogeneous distribution of functional additives in plastics matrix (right) using TD-THz (©Fh-IPM).

300 GHz and 600 GHz. For DOTNAC three different frequencies will be used in one setup: 100 GHz, 300 GHz and 830 GHz. The latter one is very novel and corresponds to the high end of the components. One of the major advantages is that the systems are all electronic systems. There is no mechanically moving part and no laser is needed. Therefore these systems promise to be industrial grade systems. They can be easily integrated into systems or on scanners, because the transceiver and detector are connected to the base unit by electrical cables only. Despite the known NDT applications (Fig. 4), only a few works of using THz technique for NDT in aviation/space are known [5]:

- The most famous one is the control of the foam isolation of the external fuel tank of the space shuttle. During the NASA program “Return to flight” the THz technique was selected above other methods during the technology discovery phase;

- Carbon fibre composites have been tested in order to detect structural defects at the surface caused by temperature in excess of 200 °C. These damages are often not obvious upon visual inspection. Even when there are visible signs of damage, it is difficult to judge the ex-tent of the damage. The THz technique was able to determine the structural integrity of the carbon fibre component.

6. Conclusions

The DOTNAC THz-NDT tool will be tested and validated on a representative variety of composite materials used in aeronautics and this for a range of commonly occurring defects. A global assessment of THz system configuration with respect to a certain defect in a specific composite material will become available.

Because of the rapidly increasing use of composites, especially in critical parts, nearly any industry (civilian and military) that fabricates and/or maintains composite structures can benefit – both in terms of cost savings and part integrity. Among a few potential applications are the non-destructive inspection of composite radomes, ship hulls, rudders and propellers.

7. DOTNAC Consortium

- Royal Military Academy (RMA) – Belgium;
- Verhaert New Products & Services – Belgium;
- Innov Support – Belgium;
- Technische Universität Kaiserslautern (UNI-KL) – Germany;
- Fraunhofer Gesellschaft e.V. (Fh-IPM) – Germany;
- CNRS – France;
- Centro de Tecnologias Aeronauticas (CTA) – Spain;
- Applus+ LGAI Technological Centre S.A. – Spain;
- CIMNE – Spain;
- Israel Aerospace Industries (IAI) – Israel.

References

[1] D. Roach, “An inspector calls”, Aerospace Testing International, 2005.
[2] F. Ellrich, T. Weinland, D. Molter, J. Jonu-scheit and R. Beigang, “Compact fiber-coupled terahertz spectroscopy system pumped at 800 nm wavelength”, Rev. Sci. Instrum., Vol. 82, 2011, p. 053102.
[3] R. Yahiaoui, H. Nemec, P. Kuzel, F. Kadlec and P. Mounaix, “Broadband dielectric terahertz metamaterials with negative permeability”, Optics Letters, Vol. 34, No. 22, November 2009.
[4] G. Chattopadhyay, K.B. Cooper, R. Dengler, T.E. Bryllert, E. Schlecht, A. Skalare, I. Mehdi and P.H. Siegel, “A 600 GHz Imaging Radar for Contraband Detection”, Proceeding of 19th International Symposium on Space Terahertz Technology, 2008, pp. 300–303.
[5] A. Redo-Sanchez, N. Karpowicz, J. Xu and X.C. Zhang, Damage and defect inspection with terahertz waves, The 4th International Work-shop on Ultrasonic and Advanced Methods for Nondestructive Testing and Material Characteriza-tion, N. Darmouth, MA, 2006, pp. 67–78.
[6] R.F. Anastasi and E.I. Mandaras, Terahertz NDE for metallic surface roughness evaluation, in: The 4th international workshop on ultrasonic and advanced methods for nondestructive testing and material characterization, 2006, pp. 57–62.

About the Author

Dr-Ing. Marijke Vandewal is Associate Professor at:
Royal Military Academy
Department CISS
Hobbemastraat 8
B-1000 Brussels (Belgium)
Tel.: +32 2 742 6563
marjke.vandewal@rma.ac.be
www.rma.ac.be

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-334

Modular Joints for Composite Aircraft Components

Llorenç LLOPART PRIETO

Abstract. Modular Joints for composite aircraft components (MOJO – Modular Joints) European research project was set to introduce a material driven design for aeronautics composite components. Composites are associated with integration, complexity, manufacturing risk, weight savings and high costs. Cost savings are achieved with out-of-autoclave infusion processes and tailored preforms made of high performance textiles. Adhesive bonding, as the most compatible joining method for composite parts, provides also significant cost and weight savings. The challenge was to create synergy between preform infusion and adhesive bonding processes supporting differential design principles. This last allows the decrease of highly integration and reduces the manufacturing risk.

Keywords. Aircraft components, 3D-woven preforms, compacting techniques, modular joints

1. The Principle of "MOJO"

The principle of MOJO lays in the design of Carbon Fabric Reinforced Plastic (CFRP) joining elements for pure shear load transfer, avoiding peel stresses. The shapes of the joining elements are defined by a number of standard attachment situations. Highly loaded shaped joints are integrated into the skin using 3D-reinforcements in order to take up out-of-plane loads. Simplified structural elements are subsequently inserted into the joints and bonded using adhesives.

MOJO focused on Pi-, H-, L- , and T-profiles (Fig. 1). The preforms were manufactured in a direct performing process using weaving and other direct technologies.

From the scientific point of view the focus is laid on the application of especially 3D-Woven preforms in order to alter the failure mechanism in favour of higher limit loads and overall improved mechanical performance (Fig. 2).

World's first industrial 3D-weaving machine became operational on 21 January 2009 heralding a major breakthrough in 5000 years of weaving history. Set to weave on a positive note, it directly wove a profile using carbon fibres in a flawless manner. This

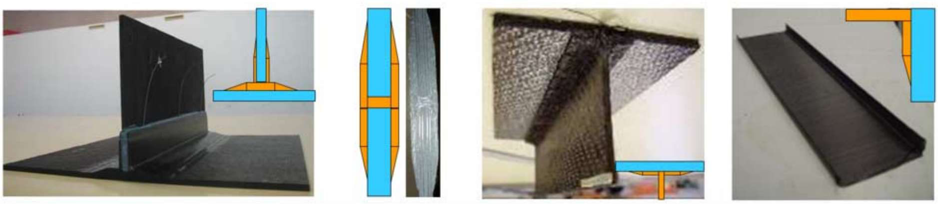


Figure 1. Modular joining elements developed and manufactured in MOJO.

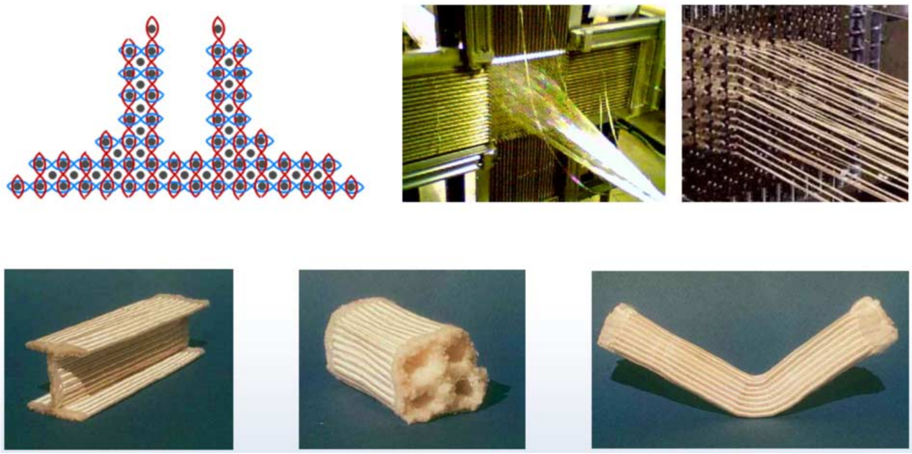


Figure 2. Possibilities of 3D-Woven performs.

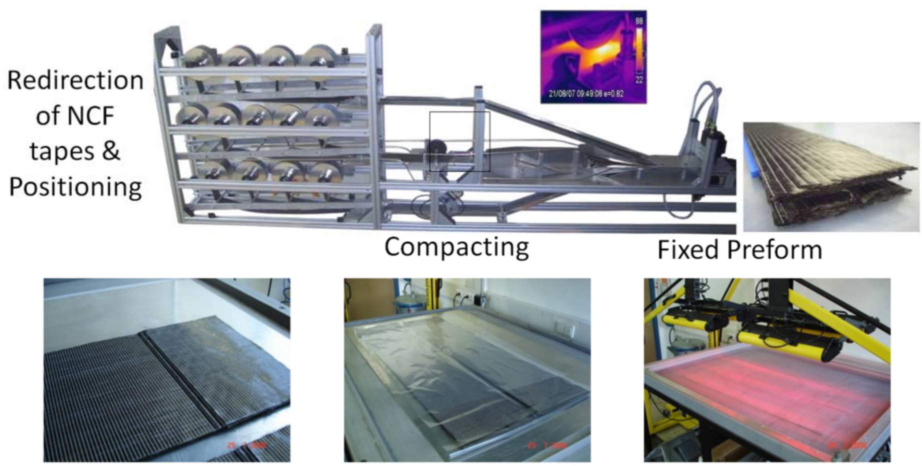


Figure 3. Preforming using compacting techniques.

first industrial 3D-weaving machine was jointly developed by Biteam AB and Department of Lightweight Structures, KTH, Stockholm, under MOJO. The 3D-weaving machine, based on the technology invented by Dr Nandan Khokar, is aimed to be gradually employed to produce advanced and complex profiles. It is designed to process a maximum of 3600 warp yarns in a 60 columns x 60 rows arrangement. Accordingly, 60 vertical wefts and 60 horizontal wefts can be inserted into the sheds of their respective directions. To produce a profile, only the necessary number of warp yarns are arranged and fed in accordance with the required profile's cross-section and the dimensions [1,2].

Different tooling, heating and cooling concepts were analysed and a preform production line was build at DLR in Brauschweig (Fig. 3). With the preform production line it is now possible to manufacture H-shaped preforms in a continuous manner and fully automatically. While using a new heating technology ("inductive heating"), the cycle time can drastically be reduced [3].

Figure 4. Types of connections, 3D-reinforced joints, and design concepts, analysed in MOJO. These alter the failure mode improving the mechanical performance.

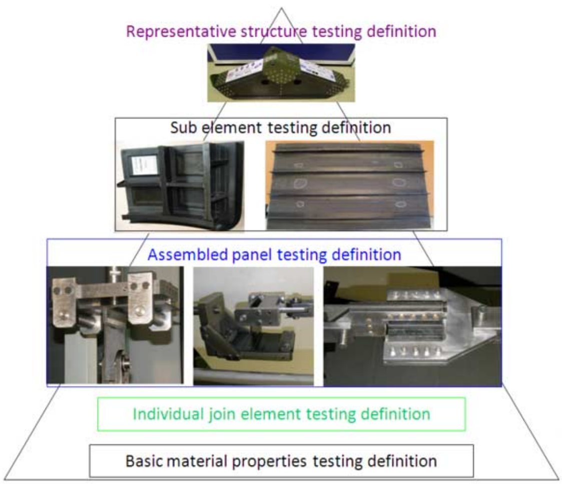


Figure 5. Determination of Mechanical performance of Modular Joints.

Stitching technology was applied in order to implement the necessary 3D-reinforcement. An integrated Velcro pin stripe (VPS) for laminate reinforcements in z-direction has been developed and manufactured as an alternative technique to the different existing stitching methods. The functionality of the VPS and the potential of z-pinning with micro carbon rods (MCR) placed in a flat carrier material have been shown (Fig. 4).

The infiltration was tried in a direct process using pultrusion. The assembly of preforms and cured parts required new strategies and methods, which have been addressed in the development of new rigs. Methods were investigated and developed in order to safely apply adhesive bonding on modular join elements to ensure cost savings [4–6]. The mechanical performance was determined with an extensive testing programme according to the Rouchon pyramid also called building block approach (Fig. 5).

All developments and tasks were supported by means of modelling and simulation: To Support adhesive bonding process & on Woven structures as well as analyse the Failure on different structure level testing. Detailed analysis descriptions can be found on the referenced publications [7–15].

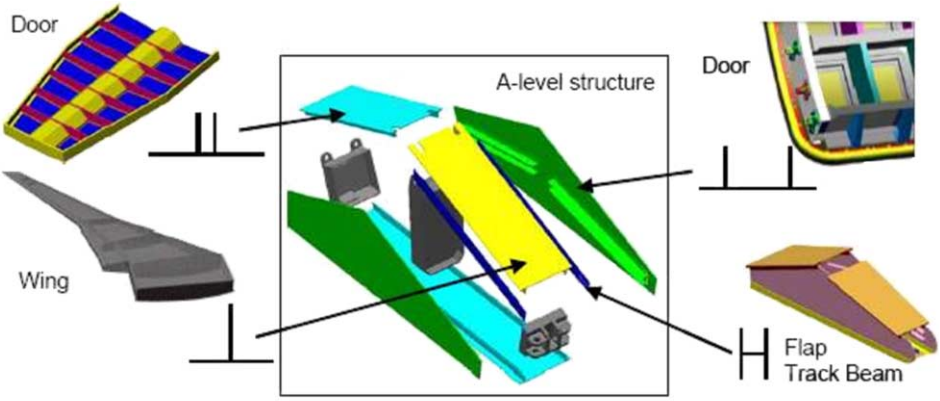


Figure 6. Choice of the demonstrator by means of the strategic industrial application of modular joints.

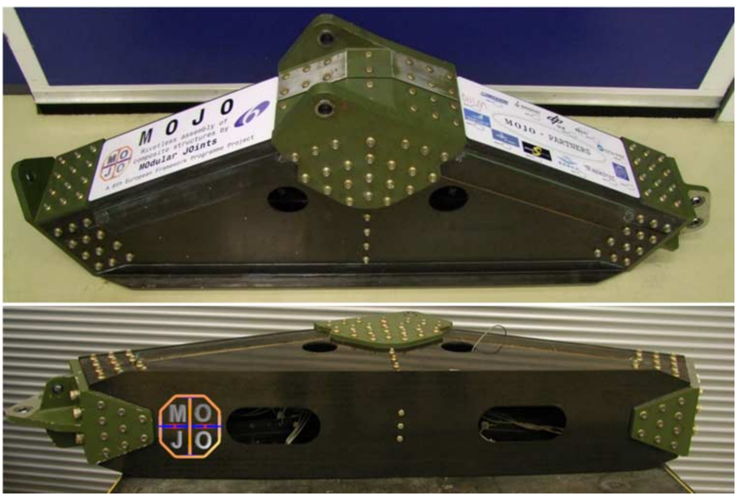


Figure 7. The MOJO – Demonstrator winner of the 2010 JEC Innovation award on Process.

The activities were complimented with an effects-of-defect research task in order to assess structural consequences of most common manufacturing damages.

The proof of the design concept has been performed by means of a full size aerospace application that featured within all MOJO developed elements (Fig. 6). It has been evaluated from manufacturing to the mechanical test. Furthermore, it has been shown that cost savings and weight savings are achieved at magnitudes of 60% in serial production study and 50%, respectively. The results have been published as guidelines and design rules including a catalogue of engineering elements supplied at European level.

The MOJO demonstrator is one of the very first representative aeronautical structures designed for assembly by structural adhesive bonding, which provides damage tolerance characteristics (Fig. 7).

It will ultimately find use in different domains by different end-users, including SABCA, Dassault-Aviation, Premium Aerotec, Cassidian and Eurocopter. Applications

will include stiffened wing-skin panels, vertical and horizontal tail planes, flap-track beams, cargo and pax doors, cargo- and pax-door surroundings, as well as unmanned air vehicles. The main components of this closed beam were manufactured with out-of autoclave infusion processes such as Resin Transfer Moulding (RTM) for the top and side panels, and Vacuum Assisted Resin Infusion (VARI) process for the lower panel.

The project could not be carried out as quickly and efficiently without a strong interdisciplinary European consortium. Indeed, it required capabilities and expertise that are spread over several countries, and all of these were necessary to gain the maximal benefit of the project: Design and preliminary production experience of 3D woven profiles and loom design and manufacture expertise are in Sweden by Biteam and Royal Institute of Technology. Preforming, infusion and bonding capabilities are mainly in Germany and France, where corresponding experience and investment already exist. Cassidian, Dassault Aviation, EADS Innovation Works, Eurocopter, German Aerospace Center, Premium AEROTEC, S.A.B.C.A and SECAR Technology. Analysis took place in Greece by University of Patras and in Australia by the Co-operative Research Centre for Advanced Composite Structures and testing at the Czech Republic by Aeronautical Research and Test Institute in organisations, which, with lower hourly rates, delivered more output for money. SME's are regarded as potential suppliers of woven profile preforms and consolidated profiles for follow on commercialisation. The project started in 2006 and was completed in 39 months.

Structural bonding is still not a widely accepted alternative to riveting. Therefore, demonstration projects like MOJO, leading to the cost and performance benefits described, will help change minds and gain a wider acceptance, opening the way to "rivetless" CFRP structures.

References

[1] Biteam's Press Release was published in a number of trade journals relating to composite materials in 2009.

[2] N. Khokar, Developing a Family of Generic Profiled 3D Textile Pre-form for Modular Construction, Airtec 2007.

[3] T. Stroehlein, S. Niemann, M. Frauenhofer, L. Herbeck and K. Dilger, Continuous Inductive Preforming for RTM-Production, 2nd International CFK-Valley Stade Convention, The Expert Forum for Lightweight Construction.

[4] J. Cinquin, H. Voillaume, T. Stroehlein and R. Ruzec, Modular joining of B-stage cured composite element with forming process and film adhesive for structural application, ICCM17, Edinburg, 27–31 July 2009.

[5] 10/08/2007: FR0705810, WO 2009 021885. J. Cinquin, Methodes of manufacturing of complex structures made of composite by assembling rigid components.

[6] 18/08/2009: FR0955699. J. Cinquin, H. Voillaume, Procédé de fabrication de pièces composites permettant une réparabilité desdites pièces.

[7] K.I. Tserpes and G.N. Labeas, Mesomechanical Modeling of Non-Crimp Fabric Composite Structural Parts, Composite Structures, accepted for publication (2008).

[8] F. Stig and S. Hallström, Assessment of the Mechanical Properties of a new 3D Woven Fibre Composite Material, Composites Science and Technology, accepted for publication (2008).

[9] P. Burka, X. Liu, J. Sheridan and M Thompson, Adhesive Flow in Composite Pi-Joints, submitted to ACCM6 the Sixth Asia-Australasian Conference on Composite Materials 23–26 September 2008, Kumamoto Japan.

[10] K.I. Tserpes and G.N. Labeas, Mesomechanical analysis of non-crimp fabric composite structural parts, Composite Structures 87, 358–369.

[11] P. Ll. Llopart, K.I. Tserpes and G.N. Labeas, Experimental and theoretical investigation of the influence of imperfect bonding on the strength of non-crimp fabric double-lap shears joints, Composite Structures, 92, 2009, 1673–1682.

[12] K.I. Tserpes, Sp. Pantelakis and V. Kappatos, The effect of imperfect bonding on the pull-out behavior of non-crimp fabric Pi-shaped joints, Computational Materials Science, 50(4), pp. 1372–1380.
[13] K.I. Tserpes and G.N. Labeas, Numerical failure analysis of a flap-track beam made of novel non-crimp fabric composites, in: Proceedings of the Composites 2009 Conference (1–3 April 2009, London, UK), Edited by S. Pinho, 2009.
[14] Sp. Pantelakis, V. Kappatos and K.I. Tserpes, Ultrasonic inspection of imperfect bonding and its effects on the mechanical behavior of NCF Pi-shaped joints, presented in: EUROMAT2009, 2009.
[15] Sp. Pantelakis, K.I. Tserpes and V. Kappatos, The effect of imperfect bonding on the mechanical performance of non-crimp fabric Pi-shaped joints: A numerical study based on ultrasonic C-scan data, presented in: ICWMM19, 2009

About the Author

Dr Llorenç Llopart Prieto
Development Engineer at Premium AEROTEC GmbH
Composite Materials & Processes (PETM)
Haunstetter Strasse 225
D- 86179 Augsburg
Tel.: +49 821 801 63727
llorenc.llopart@premium-aerotec.com
www.premium-aerotec.com

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-340

Structural Health Monitoring Systems in Airbus Military

Javier GÓMEZ-ESCALONILLA, Jorge CABREJAS and Jose I. ARMIJO

Abstract. Systematic monitoring of the health and the usage of the airframe is considered essential for continued airworthiness in most military regulations [1–3]. Although initially applied to fighters, it is now common practice for most Air Forces to require a structural monitoring program to be in place by the time every newly acquired military aircraft enters operational service, in order to increase operational availability, and to reduce costs of ownership.

Keywords. Airbus military, health monitoring, structures, usage monitoring function, operational loads monitoring functions, usage-based maintenance

1. The Aim of a Structural Health Monitoring System

From a practical point of view, the aim of a structural health monitoring system is to provide information about the usage of individual aircraft and the impact on the corresponding fatigue damage consumption of the airframe, to:

- Assess if each individual aircraft is being operated within the design usage assumptions;
- Enable structural assessments based on actual individual aircraft usage; and
- Maximise aircraft's reliability and minimize the cost of ownership, by avoiding unscheduled expensive inspections or component changes or repairs, with the associated reductions in fleet availability.

2. About Monitoring Systems Architectures

There is no standard architecture for monitoring systems. Instead, a case-by-case analysis is conducted by the air forces to select the most appropriate system for each particular platform, based on both the size and cost of the fleet, and the expected variability in usage. Over the years, the military industry has provided a range of different technical solutions of increasing accuracy and complexity to meet the different requirements. The simplest monitoring system involves recording – in many cases with a manual process based on crew forms – only several significant parameters, such as flying hours or flight cycles for each aircraft. This concept is particularly appropriate for long-range transport aircraft where the operational role is well defined. When operational roles vary, the former approach is expanded to record other significant parameters that may contribute to fatigue damage, for example, weight and stores configuration.

However, probably the most popular structural monitoring system is still the 'fatigue meter'. This device just registers counts of the acceleration in the vertical axis at

the aircraft centre of gravity, which is useful to define the loading the airframe is subjected to. To relate component stresses to loads, the output of the fatigue meter is combined with the collection of the significant parameters explained before.

It must be pointed out that the 'fatigue meter' is only good for measuring loads in components where there is good correlation between 'g' levels and stresses in the structure, basically the inner wing and parts of the centre fuselage. However, this concept takes no account of rolling or yawing, nor does it provide data to measure the loading in structure which is not related to vertical accelerations at the centre of gravity, so the assessment of elements such as the rear fuselage or the tail plane has to be performed in terms of flight hours or flight cycles only.

The collection of basic flight data and the fatigue meters are complemented in some cases by Operational Loads Monitoring (OLM) programs. The objective of these programmes is to obtain time history records of strain data so that the actual loading can be determined for the critical areas of the airframe. A representative sample (e.g., 10 or 20%) of operational aircraft is usually instrumented for this purpose. OLM programs are usually not permanent, being conducted with a predefined periodicity or reintroduced when the changes in operational usage that may affect the loading environment are identified.

3. The Structural Health Monitoring System (SHMS) Developed by Airbus Military

In recent years, all these approaches have been progressively replaced by modern flight recorders capable of collecting both flight and strain data. With these devices, structural loads can be derived directly from the data obtained from a fleet-wide instrumentation while the flight data provides the ability to identify typical operational profiles of the fleet, useful to investigate usage patterns. However, the great capability of such systems is at the same time their main drawback, as they are costly to develop and support. The Structural Health Monitoring System (SHMS) developed by Airbus Military for the C-295 – a high wing, pressurised, twin turboprop tactical transport aircraft capable of operating from short, unpaved runways – and the A330-MRTT – Multi Role Tanker Transport, a conversion of the civil A330-200 platform into a tanker version – are an evolution of this family of systems, in an attempt to keep their major advantages while minimizing their own life cycle costs [5].

3.1. The Architecture

The SHMS is essentially a combination of sensors, data acquisition technology and algorithms (Fig. 1). It is composed of a fleet-wide recorder for the collection and storage of flight data from the avionics of the aircraft, and a centralized ground unit capable of analyzing and reporting aircraft usage, and of performing a periodic calculation of fatigue damage consumption for individual units of the fleet. The system has also a range of mechanisms to detect malfunctions and, within reasonable levels, correct them.

The architecture of the SHMS consists of two main functions. On one side, the Usage Monitoring Function (UMF), which is based on the acquisition and assessment of pertinent flight data (e.g., velocity, accelerations, altitude, fuel usage, etc.) to identify changes in the usage pattern of individual aircraft from that originally planned.

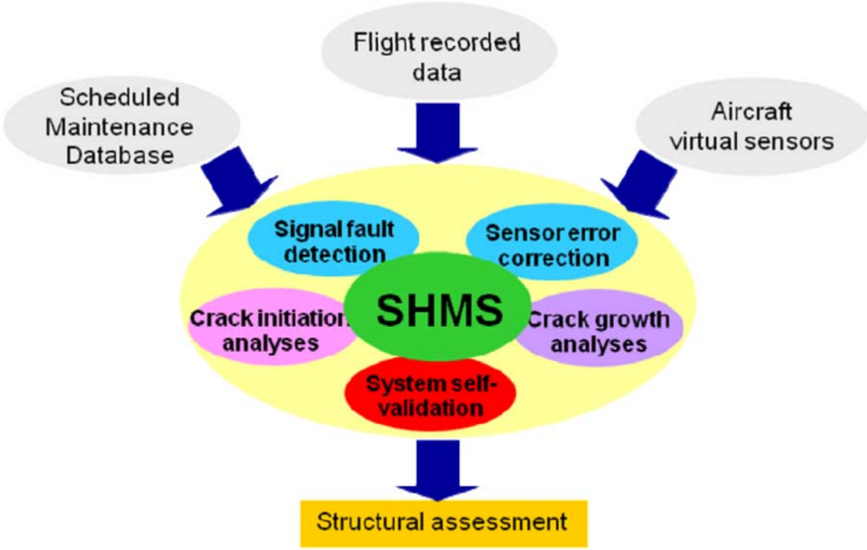


Figure 1. Structural Health Monitoring System concept.

Figure 2. Virtual sensors arrangement in C-295 and A330-MRTT.

On the other side, the Operational Loads Monitoring Function (OLMF) aims at the acquisition of the information necessary to define the actual loads experienced by the aircraft structure. Unlike in other systems, the OLMF is not based on physical sensors, but on a set of virtual strain gauges derived from either analytical models or by using Artificial Neural Networks [4]. This solution overcomes the main disadvantages of other modern structural monitoring systems, because the virtual sensors minimize the installation and maintenance costs, reduce to a minimum the list of embodied elements therefore minimizing the costs, and maximize the reliability of the sensors.

The initial number and location of those virtual sensors has been determined after an analysis of the structural components that must be monitored for airworthiness reasons. Additional sensors have been included in order to have flexibility to monitor, for example, future structural modifications due to the installation of new systems, which is a quite usual practice in military aircraft. The virtual strain gauges can also be used to track structural repairs, or components or structure which would benefit from a monitoring program due to their time and cost of replacement. The result is a dense network of sensors covering all the main load paths in the different components of the aircraft (Fig. 2).

The information collected by the virtual sensors is processed in terms of fatigue damage consumption and crack growth rates in the selected locations. The outputs are provided in the form of updated inspection thresholds and intervals for the relevant tasks of the maintenance program.

3.2. The Usage-Based Maintenance Concept

The capabilities of the SHMS enables the Usage-Based Maintenance (UBM) concept, in which customized actions can be taken for individual aircraft operating at a different than anticipated scenario, thus optimizing the operating costs and preventing further costly damages. This concept represents a major improvement with respect to the static current practices and significantly improves the reliability and availability of the fleet, while allowing a tailored management of the safety. Thus, the damage tolerant structure of the C-295 and A330-MRTT – cleared by an inspection-based regime – can have more accurately defined inspections, allowing actions not achievable with the standard approach, such as tailored periodicity of inspections for each individual aircraft or particular management of inspections during deployments.

Although in the literature is usual to identify the term 'Structural Health Monitoring' (SHM) with the development of techniques and systems for damage detection to report the condition of aircraft, the UBM concept can be considered already as a true SHM technique in the sense that in the military aviation it is preferred a complete prognostic capability in order to understand how the operational roles – either current or future – of the aircraft impact on the fatigue damage accrual of each individual aircraft, and how a tailored maintenance and fleet management can help to preserve the aircraft to its planned withdrawal date without unforeseen unit retirements.

4. Future Developments

The current functions of the SHMS explained above (i.e., Usage Monitoring Function and Operational Loads Monitoring Function) could be complemented in the future with a third one called Condition Monitoring Function (CMF), by means of the installation of sensors having the capability to automate the structural inspections. The incorporation of these sensors will be highly selective, initially focused on components prone to accidental damage, in elements needing temporary frequent inspections or in locations in which standard inspections are costly. With this new function, the Usage-Based Maintenance (UBM) approach will be evolved to achieve the Usage+Condition Based Maintenance (U+CBM), in which the combination of diagnostic and prognostic capabilities of the system will represent a new paradigm for structural maintenance of the Airbus Military products.

5. Conclusion

The Structural Health Monitoring Systems developed by Airbus military for the C-295 and the A330-MRTT have been conceived to be the essential part of a routine reporting framework about the structural life of individual aircraft and/or aircraft components, while minimizing at the same time the development and maintenance costs of the system itself. The design of the outputs enables the Usage-Based Maintenance (UBM)

concept, providing sufficient feedback to both engineering and operational staffs for structural integrity and fleet management purposes, respectively.

References

[1] Australian Air Publication 7001.054, Airworthiness Design Requirements Manual, 06 Jun 2007.
[2] DEF STAN 00-970, Design and Airworthiness Requirements for Service Aircraft, Part 1, 31 Jan 2011.
[3] MIL-STD-1530, Aircraft Structural Integrity Program (ASIP), issue C, 01 Nov 2005.
[4] J. Gómez-Escalonilla, J. García, M. Andrés and J.I. Armijo, Strain predictions using Artificial Neural Networks for a full-scale fatigue monitoring system, 6th DSTO International Conference on Health and Usage Monitoring, Melbourne, Australia, 2009.
[5] J. Gómez-Escalonilla, J. García, J. Cabrejas and J.I. Armijo, A full scale parametric-based fatigue monitoring system using neural networks, 24th International Committee for Aeronautical Fatigue (ICAF) Symposium, Naples, Italy, 2007.

About the Authors

Javier Gómez-Escalonilla
Javier.Gomez-Escalonilla@military.airbus.com
Jorge Cabrejas
Jorge.Cabrejas@military.airbus.com
Jose I. Armijo
Jose.Armijo@military.airbus.com
Airbus Military
Fatigue and Fracture Mechanics Department
P° John Lennon s/n
28906 Getafe (Madrid), Spain
www.military-airbus.com

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-345

LTCC: A Packaging Technology Suitable for High Density Integration and High Temperature Applications

Conor SLATER

Abstract. The objective of the European research project "CREAM" – Compact and Reliable Electronic in Actuators and Motors – is to reach new high performance and reliability capabilities of Electro-Mechanical Actuators (EMA) in harsh thermal environmental conditions for use in All-Electric Aircraft (AEA). High Thermal stability, the ability to package a high density of components and interconnects, the possible integration of thick film resistors and a variety of high temperature component attach, and interconnect technologies make LTCC– Low Temperature Co-fired Ceramic – a suitable candidate for the packaging of control electronics for high temperature applications.

Keywords. Electro-mechanical actuators, all electric aircraft, low temperature co-fired ceramic, compact electronics

1. Introduction

The current political, environmental and economic trends applied to air transport will cause a shift in aircraft design to the All Electric Aircraft (AEA). The goal of this concept is to eliminate as many hydraulic power sources and complicated circuitry of high-pressure hydraulic lines as possible and use Power By Wire (PBW) to provide electrical power straight to the actuators. This design approach would reduce the weight and complexity of commercial aircraft thus reducing the fuel consumption and maintenance costs.

However the maturity of PBW technology is lagging behind. As a matter of fact, reliable electric actuators are one of the technical bottlenecks for realizing this ambitious technological vision of all electrical aircraft. The real challenge is the development of compact, reliable, Electro-Mechanical Actuators – EMA (flight control actuators, braking system, landing gear actuators, propulsion inverters, various pumps, various auxiliary actuators). The "Compact and Reliable Electronic Integrated in Actuators and Motors" (CREAM) project objective is to reach new high performance and reliability capabilities for Electro-Mechanical Actuators (EMA) in harsh thermal environmental conditions for use in all-electric aircraft.

For this global objective, the target is to develop an advanced, smart, miniaturised and reliable electronic technological platform (Fig. 1) integrating new compact technologies, advanced components and assembly methods able to substantially improve the drive and control electronic modules and the EMA motors in order to provide compact electronics, thermal management above 200°C with enhanced reliability.

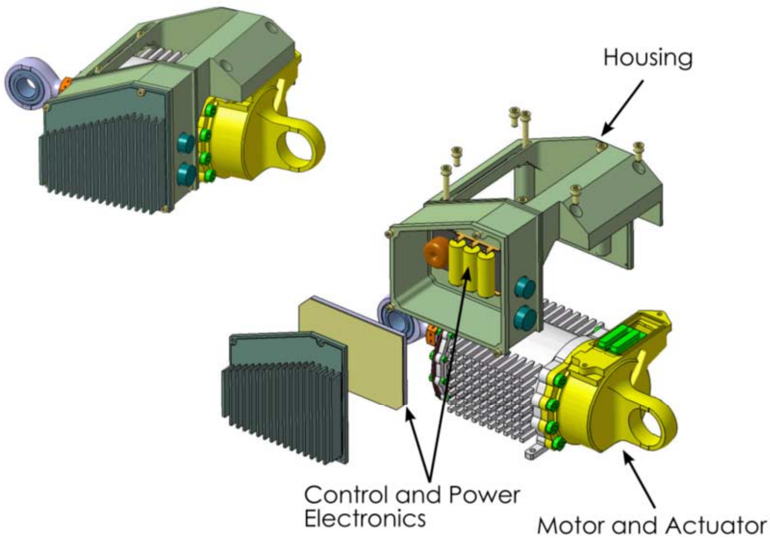


Figure 1. CREAM-Electromechanical actuator with exploded view.

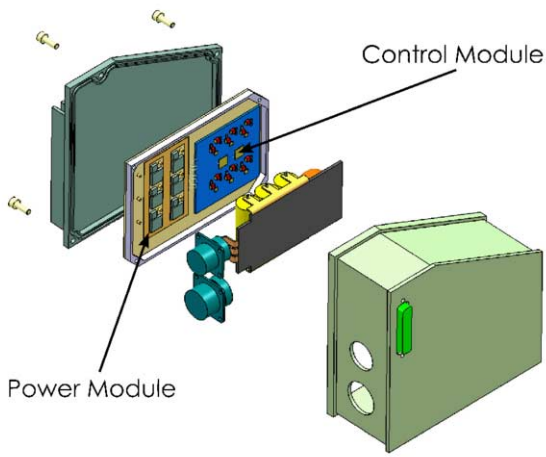


Figure 2. CREAM multi chip power module.

The subsystems of the EMA have to be capable of operating in an extreme environment, with low and high temperatures ranging from –65 to +200°C. The constraints set do not allow the use of active cooling methods, therefore the technology developed must be able to operate unassisted in this temperature range. In addition to this challenge the lifetime of the actuator should be in the order of 100,000 hours. Due to the compact design, the power and control electronics are mounted together (Fig. 2) subjecting the control module to harsh temperature conditions. The substrate required to package the electronics for this module must have mechanical stability, good thermal conductivity and low dielectric loss at temperatures up to and over 200°C and down to –65°C. The next criterion is the ability to mount a high density of components of different types and route complex network of interconnections.

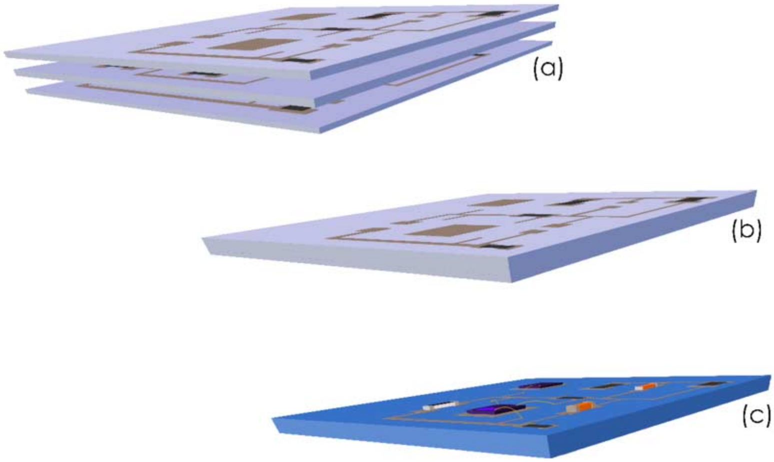


Figure 3. The LTCC process: (a) Collation of screen printed sheets; (b) Lamination; (c) Firing and component population.

Low Temperature Co-Fired Ceramic (LTCC) is a technology where thin dielectric tapes are laminated together and fired to create a monolithic ceramic substrate. The post fired product remains stable at temperatures up to 450°C and as it is a multilayer technology a high density of conducting tracks can be routed [6]. The great advantage of LTCC substrates is the ability to integrate passive components, such as resistors, capacitors and inductors between the dielectric layers which allows for compact modules to have a high degree of functionality.

2. LTCC Manufacture

The raw LTCC is manufactured as a tape which consists of glass frit, alumina powder and an organic binder. The tape is cut to the correct size and has vias and cavities cut into it by either shearing, punching, direct milling or laser ablation to form the different layers of the LTCC module. Next the vias are filled by screen printing conductive filler into the holes cut into the LTCC, and then each layer is screen printed with conductive tracks and resistive elements. Each of the LTCC layers can be fabricated separately up to this point in the process, it is only at the lamination step that all the layers are brought together, aligned and stacked, and then pressed together (Fig. 3). The entire assembly is then fired at a temperature between 800 to 1000°C to sinter LTCC module. Standard thick film methods can then be used to post fire additional conductive layers and resistors on the surface, after which discrete components can be mounted on top.

3. Integrated Passive Components

Thick film resistors integrated into the substrate have proven to be a key feature of LTCC. Furthermore these resistors show good stability at temperatures up to 200°C, but there is a limit to the precision mainly due to drift caused by diffusion of the contact metal into the resistor [5]. The resistors have a simple construction consisting of

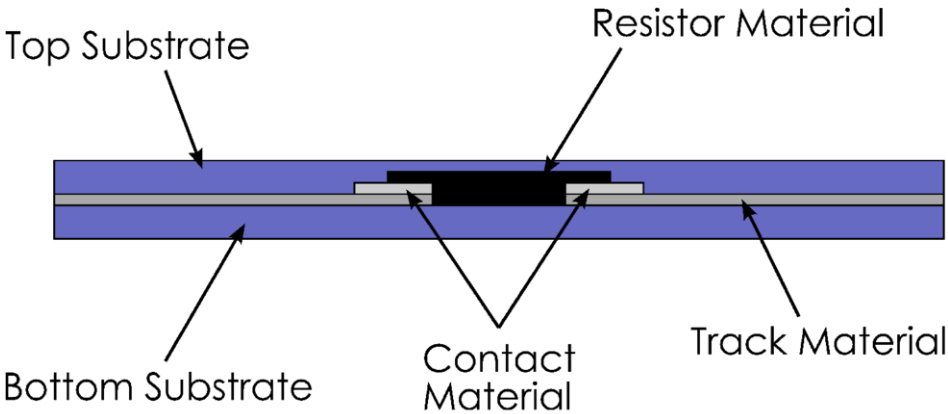


Figure 4. Integrated passive component.

two contacts between which the thick film resistor is screen printed. The resistor is printed on a single layer of LTCC after which it can be stacked as in (Fig. 4) with other layers before lamination. After firing, the resistor is 'buried' within the substrate which gives it interesting properties in terms of high temperature resistance. Research has shown that burying the resistor between layers of LTCC enhances the stability of the resistive material due to the LTCC layer protecting the resistor from oxidative effects which would be more pronounced at high temperatures [2].

Capacitors and inductors have seen less success but it is still possible to integrate these components directly into the substrate. Capacitors are assembled by screen printing electrodes on two separate LTCC layers and stacking them on top of each other. For high capacities the construction requires special LTCC tape with high permittivity so they are not widely used. Inductors are problematic as well since they require fine dimensions for the conductor and special high permeability LTCC layers.

4. Component Packaging Methods

The materials required to mount the module components will have to undergo extreme conditions and survive thousands of temperature cycles with extreme high and low temperatures while the EMA is operating. This causes fatigue in the joints and with high temperatures causing the material to degrade over a long period of exposure. It is clear that the substrate to mount them will have to be flexible enough to accommodate the packaging technology peculiar to each type of component. Components for the control module fall into the categories of either a mounted passive component, such as a multilayer ceramic capacitor or a metal thin film resistor, or an integrated circuit in the form of a silicon die.

Discrete passives (Fig. 5) have two contacts which can be composed of a variety of materials. The component is mounted between the terminations and bonded to the contact material. The material/technique used for bonding must provide mechanical attachment and electrical contact. It must also not stress the component mechanically causing it to fail or to damage its metallisation.

The die attach has a vertical planer construction as in Fig. 6. Starting at the substrate a metallisation layer is placed on top, then there is the bond material followed by

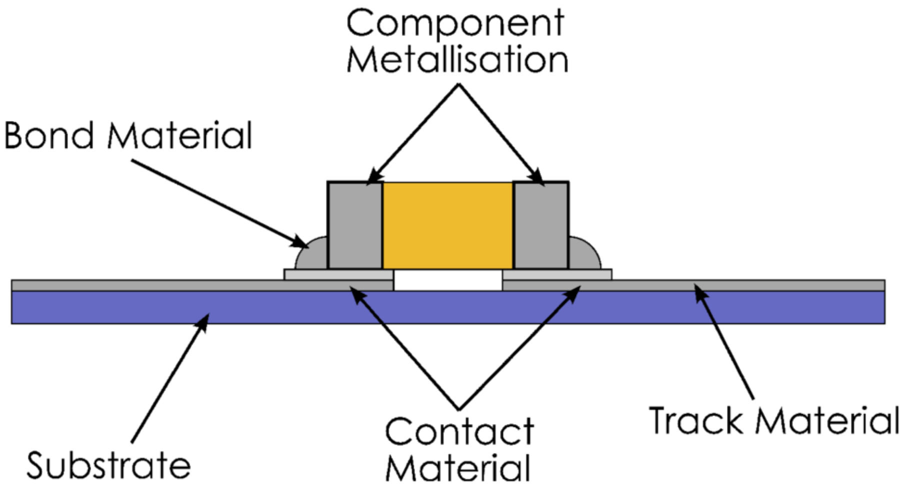


Figure 5. Discrete passive component.

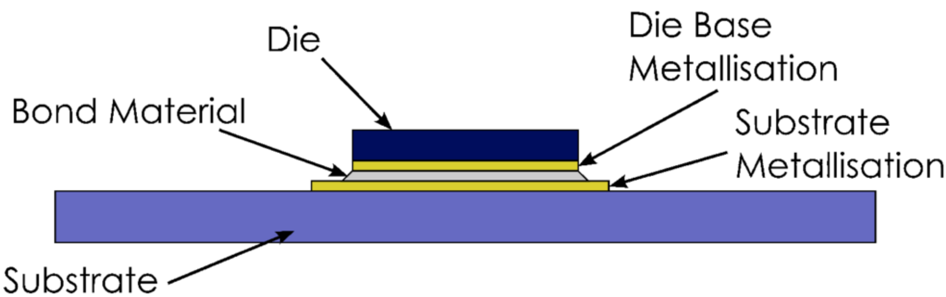


Figure 6. Mounted Die.

the metallisation on the underside of the die. The metallisations are not necessary if they are not required by the bond material to form an attachment. Whichever configuration is used the bond must provide mechanical attachment of the die and have sufficient thermal conductivity dissipate the power consumed by the die.

The most common method for attaching electronic components is by use of a solder alloy. The alloys used have melting temperatures that range between 90 and 450°C, which implies that a suitable solder can be found for mounting components in the CREAM EMA. However many of the high temperature solders contain valuable metals such as gold and can be prohibitively expensive with the exception of high lead solders (>85% Pb), which are commonly used as high temperature die attach methods. If properly employed the solders can form very strong bonds and can have excellent electrical and thermal conductivity. The main cause of failure is due to thermo-mechanical crack growth along the solder joint weakening its bond strength and reducing its thermal conductivity. Growth of the crack can be exacerbated by creep at high temperatures and, to a much greater extent, by CTE mismatch of the materials in combination with extreme temperature variations. Furthermore the solder alloy itself can be weakened by the growth of brittle intermetallics causing crack growth to increase which in turn reduces the lifetime of the joint [1].

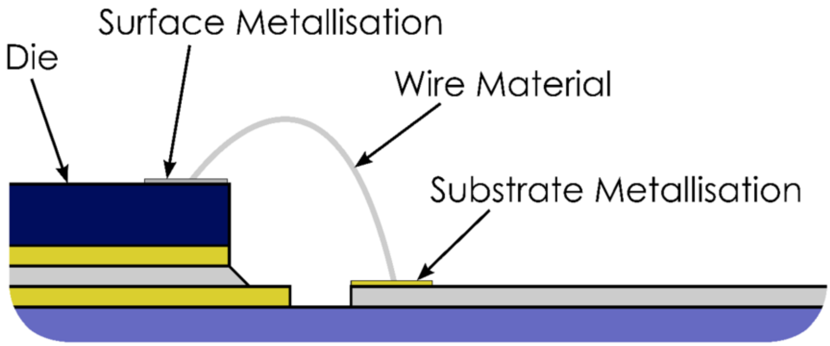


Figure 7. Wire bond.

Transient liquid phase (TLP), also known as diffusion soldering, is a method where a thin interlayer is clamped between the metals to be joined. The system is then heated up to the temperature where the interlayer melts, at which point it inter diffuses into the metals forming intermetallic compounds. These intermetallics are solid at the melting temperature of the interlayer, which means the joint solidifies isothermally. The end effect is a joint that has a higher melting temperature than its processing temperature. This process differs from diffusion bonding in that the interlayer has “transient liquid phase” which allows voids to be filled in. The advantage of TLP is that the bond is made by forming intermetallic compounds which give the joint its strength. However, the difficulty is to choose the right combination of metals to satisfy the process criteria, and that do not form brittle intermetallics. Once formed though, the bond holds its strength even after long term high temperature storage, and can even increase in strength as the intermetallics continue to form and bond becomes more homogenised over time [7].

Polymers being organic materials are generally not suited to high temperature applications, but there are a few exceptions such as silicones and epoxies that can operate in the 200°C to 300°C range. These materials used excel in situations where components of different CTEs are to be mated and this is owed to their flexibility. However, polymers have very poor thermal conductivity so are not suited to mounting components which dissipate large amounts of power unless they are filled with thermally conducting materials. In addition they also have no inherent electrical conductivity which means they have to be modified by filling with conductive materials if they are to form contacts for components.

Silicon components with logic functions such as in the control module for the CREAM EMA usually have a large number of interconnections that are densely arranged. This makes interconnection technologies such a flip-chip not feasible due to the small size of the pads and the narrow pitch between them. Wire bonding is traditionally used for providing a high density of interconnects but it can be problematic at temperatures above 200°C (Fig. 7) shows the construction of a wire bonded interconnect from a silicon die to the metallisation on the substrate. The three materials of concern are the surface metallisation of the die, the wire material itself and the metallisation material of the substrate.

In wire bonds, failure of the bond is caused by fatigue cracking which is brought on thermal cycling and the CTE mismatch of the die and the wire material. This failure mechanism can be made worse due to the formation of brittle intermetallics and Kir-

kendall voids at high temperatures. For example, Gold-Aluminium systems quickly form brittle intermetallics when exposed to temperatures above 200°C which would leave them unsuitable [8]. Conversely Al-Al wire bonds, being of the same material, do not form intermetallics and thus show good high temperature performance. Aluminium bonds can also be given enhanced resistance to fatigue induced by thermal cycling by integrating a molybdenum strain buffer which reduces the effect of the CTE mismatch [3].

Common to all the packaging techniques stated is the need for the optimum material at the bond interface. As LTCC is compatible with thick film processes there is a wide selection of materials to choose from such as noble metals (e.g. Platinum, Gold, Silver and Palladium). With LTCC it is possible select the best material for the application. For example selecting the best pad material for a solder joint to reduce the formation of intermetallics or in the case of TLP select the correct material to form the joint. Other advantages of LTCC is that its coefficient of thermal expansion (CTE) is close to that of silicon and the ceramics used in discrete passive components which reduces the stresses on the mounted component and the material used to attach it, which would reduce the effect of reliability issues such as cracking in solder joints.

Despite the variety of materials available use of non-noble metals such as aluminium can be problematic due to oxidation of the conductor during firing. If aluminium wire bonds are used there is no contact material that is directly compatible with both LTCC and the wire material. Alternatives such as Gold-Palladium pastes show good performance with aluminium wires but a feature of LTCC is that it can be combined with thin film processes to create barrier layers. High temperature Aluminium-Silver wire bonds were demonstrated by depositing a thin Nickel-Gold barrier layer on the silver pad before the aluminium wire was bonded. This allowed for long bond life at temperatures up to 250°C [4].

5. Conclusion

The CREAM EMA presents many challenges it terms of performance at high and low temperatures and reliability over long periods of time. Particularly where the control electronics are involved as this subsystem consists of a high number of components of varying types. This large variety of technologies requires a highly flexible substrate technology to integrate them into a functional and reliable module. LTCC being a multilayer technology allows a high level of complexity and integration. This coupled with its high temperature stability make it an ideal technology for a high temperature control module.

The flexibility of LTCC and its compatibility with a wide array of materials also allow it to be used with a large variety of components each with their own unique packaging problem. Solders and adhesives are readily compatible and even in the case of wire bonds the compatibility of LTCC allows for realistic workarounds. If future systems such as actuators for aircraft that operate in harsh environments are to become increasing smart, LTCC will have a key role in securely packaging their complex control electronics.

Acknowledgements

This work is funded by the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement AAT.2008.4.2.4-234119 CREAM

References

[1] N. Duan, J. Scheer, J. Bielen and M. van Kleef, The influence of Sn-Cu-Ni(Au) and Sn-Au inter- metallic compounds on the solder joint reliability of flip chips on low temperature co-fired ceramic substrates, Microelectronics Reliability, 43(8):1317–1327, 2003.

[2] A. Dziedzic, L. Golonka, M. Hrovat, J. Kita, M. Kosec and D. Belavi, Some remarks about relations between processing conditions and microstructural, electrical as well as stability properties of LTCC resistors, in: European Microelectronics and Packaging Symposium, Prague, Czech Republic, 2004.

[3] A. Hamidi, N. Beck, K. Thomas and E. Herr, Reliability and lifetime evaluation of different wire bonding technologies for high power IGBT modules, Microelectronics Reliability, 39(6–7):1153–1158, 1999.

[4] R. Johannessen, F. Oldervoll and F. Strisland, High temperature reliability of aluminium wire- bonds to thin film, thick film and low temperature co-fired ceramic (LTCC) substrate metallization, Microelectronics Reliability, 48(10):1711–1719, 2008.

[5] R. Johannessen, F. Oldervoll, F. Strisland and P. Ohlckers, Performance of thin and thick film resistors exposed to high temperature and high pressure (200°C @ 1000 bar), in: HITEN 2007, Oxford, UK, pp. 678–682, 2007.

[6] B. McPherson, J. Horberger, J. Bourne, A. Lostetter, R. Schupbach, R. Shaw, B. Reese, B. Rowden, A. Mantooth, S. Ang, J. Balda, K. Okumura and T. Otsuka, Packaging of high temperature 50 kW SiC motor drive modules for hybrid- electric vehicles, Advancing Microelectronics, 2010.

[7] H.A. Mustain, W.D. Brown and S.S. Ang, Transient liquid phase die attach for high-temperature silicon carbide power devices, Components and Packaging Technologies, IEEE Transactions on DOI – 10.1109/TCAPT.2010.2046901, 33(3):563–570, 2010.

[8] E. Philofsky, Design limits when using gold-aluminum bonds, in: Reliability Physics Symposium, 1971, 9th Annual DOI – 10.1109/IRPS.1971.362502, pp. 114–119, 1971.

About the Authors

Conor Slater, B. Eng, M. Eng,
Doctoral Assistant
Laboratoire de Production Microtechnique
Ecole Polytechnique Fédérale de Lausanne
Station 17
CH-1015 Lausanne (Switzerland)
Tel.: +41 (0)21 693 78 98
conor.slater@epfl.ch

Paul Vassy
Programme Manager – CREAM Project Coordinator
SAGEM Groupe SAFRAN- Etablissement François Huguenot
100, rue de Paris
F- 91344 Massy Cedex (France)
Tel.: +33 (0)1 58 11 35 81
paul.vassy@sagem.com

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-353

Towards the More Electrical Aircraft

Etienne FOCH

Abstract. Taking benefits from breakthroughs in the rapidly-expanding power electronics market, the European Aerospace Industry developed a full suite of more electronic technologies, for a More Electrical Aircraft. Tests at vendor and air-framer facilities demonstrated that the fully-integrated system worked and performed as intended. Major test objectives were successfully passed. Conceptual design studies concluded that the concept may readily deliver aircraft benefits in terms of maintenance, operational, flexibility and technology growth potential. Furthermore, as more electrical technology is friendlier for the environment, the "MOET" (More Open Electrical Technology) concept appears as a key enabler for future aviation development, and as in other industry sectors, it is step by step becoming the new standard for onboard aircraft systems.

Keywords. All-electrical concept, micro-hybrid, more-electrical technology, electrical networks

1. Introduction

The move to More Electric technology in the automotive industry is not easy. Solutions range from micro-hybrid to all-electric. Environmental benefits are emphasized. All-electric cars have a limited range compared to vehicles with a conventional internal combustion engine. Investment costs are huge.

The rationalization of energy sources aboard 100-plus passenger aircraft and improvements in More Electric technology are leading the aeronautical industry to tackle the all electric aircraft challenge. This change will only occur if the proposed solutions offer advantages over existing solutions, which are simple and mature. As in the automotive industry, this change will require a complete redesign of the architecture of on-board power generation systems, from the design phase to industrialization, never losing sight of the end user needs, namely, the airline.

2. What Does "All-Electric" Aircraft Mean?

All aircraft systems require electrical power and are becoming more and more electric. The main power generators produce 180kVA on an A320 and 600kVA on an A380, i.e. approximately 1kVA per passenger.

The aim of an aircraft commonly known as "all-electric" is not to replace power plants by electric motors driving fans whose power would be in the range of 10MW. This highly prospective idea is not covered in this article as we are staying on much more concrete ground.

Figure 1. The consequences of electrification of these power networks depend on their type.

The “all-electric” concept consists in the electrification of all aircraft systems. Currently, the systems are supplied by four power networks of a very different nature:

- The avionics system, some pumps, the fans, the lighting and the furnishings systems in cabin use electrical power;
- The cabin pressurization and air conditioning systems use air bleed from the engine compressor stages after recycling in an air conditioning pack. Hot air bleed at the engine outlets is also used for wing de-icing. Pneumatic power is also used for engine starting. These are the largest power consumers;
- The flight control and landing gear systems are actuated by hydraulic actuators supplied by engine-driven pumps, or by electric pumps supplied by the electrical network;
- Fuel supply to the engines, as well as lubrication, are provided by pumps driven by the engines via a mechanical shaft.

Figure 1 shows what an “all-electric” aircraft energy chain could look like.

2.1. Replacement of the Pneumatic Network

Cabin air no longer comes from the engines but from specific air inlets that supply electrical air compressors supplying two packs (Air conditioning pack on preceding figure). Wing de-icing (Electrical wing de-icing) uses heater mats. The engines are started electrically by generators acting as starter/generators (main power supply).

The power required is multiplied by four compared with current aircraft. This level of power requires increased voltage values and the introduction of power electronics to control the electrical compressors, engine starters, and also ensure temperature control of the wing de-icing mats. Boeing addressed this challenge on their latest B787 aircraft.

2.2. Replacement of the Hydraulic Network

Aircraft usually have three hydraulic systems in order to meet the certification criteria as regards redundancy and segregation. Hydraulic power has a very high power density and is well suited to confined areas such as the stabilizers and wing ends. The flight control and landing gear systems must respond rapidly to high power demands during landing gear extension or retraction, or for certain manoeuvres commanded by the pilot.

In electrical solutions, the hydraulic actuators are replaced by electro-hydraulic or electro-mechanical actuators driven by power electronics (Flight control electric actuators). These new actuators are bigger and more difficult to install, however, they allow rigid hydraulic pipes to be replaced by electrical circuits whose installation is more flexible. The dynamic performance of these actuators is comparable to that required of hydraulic actuators.

This stage was already partially reached by Airbus on its A380 on which a hydraulic system among three was replaced by a set of electro-hydraulic actuators powered from the electrical network.

The removal of the hydraulic network will, by nature, eliminate the need for hydraulic fluid that is harmful to the environment.

2.3. Replacement of the Mechanical Network for the Fuel and Oil Pumps for the Engine

This network is a simple mechanical shaft usually driven by the engine HP turbine, which drives an accessory gearbox. It drives the pumps and also the electrical generator(s), hydraulic pump(s) and air starter. The accessory gearbox is attached to the engine. The deletion of this shaft requires integration of the starter/generators in the engines to supply all accessories via power electronics and electric motors.

A demonstrator of this solution was produced and tested by Safran and Thales as part of the POA European project on a Rolls-Royce Trent 500 engine. The economic performance is not demonstrated.

3. Electrical Network Challenges

The challenges related to replacement of pneumatic and hydraulic networks are a good opportunity to rethink the electrical architectures of aircraft.

3.1. Current A320 Network

An A320 type network includes two main generators of 90kVA/115VAC-400Hz, each one driven by an engine. This network supplies all the electrical loads of the aircraft.

If the main electrical generation is lost in flight, a standby generator supplies power to the electrical systems for continued safe flight operation. This standby generator receives hydraulic power from a Ram Air Turbine (RAT) that also supplies power to the flight control actuators.

An "all-electric aircraft" concept will involve changes in this network, through the application of strategies adapted to replacement of the pneumatic and/or hydraulic networks.

3.2. Replacement of the Pneumatic Network

The power required and the control of large electric motors using power electronics to be integrated in an aircraft constitutes the challenge.

The choice of a higher voltage adversely affects compatibility with the existing ground power units, or standard equipment, especially in the cabin, however, this represents an opportunity for the creation of a new standard. 230VAC is a standard which has been selected by some last aircraft development. By definition, an aircraft flies and the partial discharge phenomena must be understood and mastered as they increase as the voltage increases and the pressure decreases with altitude.

It is also advisable to consider +/–270VDC high voltage directly obtained via rectification of 230VAC. The arc rupture capability using HVDC electromechanical contactors has been demonstrated by Zodiac. The issues related to stability, quality and selectivity of protections have been examined with research laboratories. No deadlock was identified.

Power electronics is a key technology. A power density of 5kVA/kg already seems established through research work, however, full integration including filters and cooling system could reduce this density to 2kVA/kg. Research work on high temperature components and thermal management is a determining factor to achieve a better overall performance.

3.3. Replacement of the Hydraulic Network

The challenge is twofold: reliable uninterrupted supply of electrical power and increased risk of jamming due to the introduction of electro-mechanical actuators.

According to the aviation regulations, the probability of losing power supply to the flight controls for a few seconds must remain extremely low. Therefore, there must be an electrical transition between the loss of the normal power supply and the start of the standby power supply lasting for several seconds. A battery or supercapacitor-type storage would be compatible with the flight control requirements. This storage can also be used to meet high power demands from the flight controls, so as to optimise the rat size. Integration of these functions is facilitated by an hvdc network.

Experience shows that, while a hydraulic actuator never jams, an electromechanical actuator is more vulnerable to this type of failure. The use of adequate materials and monitoring devices to anticipate jamming could limit the risk without fully eliminating it. Therefore, architectures that are tolerant to this type of failure must be developed.

3.4. Other Electrical Sources

Fuel cells are among the other electrical sources studied. Replacement of the standby generator is technically feasible. This solution has already been tested on an A320.

Replacement of the APU requires a large amount of power involving either the use of large capacity hydrogen tanks or a fuel reformer, hence a significant weight penalty. The benefits would be clean operation on ground. It is also to be noted that by nature, a fuel cell can be connected more easily to HVDC network than to HVAC that would require addition of inverters.

Note. The APU (Auxiliary Power Unit) is an onboard turbine that supplies power to the aircraft systems when the aircraft is on ground with its engines stopped.

4. Assessment at Aircraft Level

In an "all-electric" aircraft, simple and mature systems with low progress capability are replaced by more complex, better suited systems with a larger progress capability.

4.1. Assessment of Savings on a Typical Mission

The aircraft mission is well characterized and starts with flight preparation, then take-off, climb, cruise, descent, landing and return, up to engine shutdown. Assessment of fuel consumption is complex, and depends on system weight, drag induced for renewal of cabin air and the impact of electrical consumption on the engines.

The expected savings mainly concern fuel consumption and they are both economic and ecological. To give an approximate idea, on a Paris-Toulouse flight, 1% fuel saving represents 25kg. This represents 500 tons of fuel for 20,000 flights (i.e. one year's operation for the Paris-Toulouse shuttle). It is therefore difficult to give a precise assessment of the savings as the impact of bleed air or mechanical/electrical off-takes on the engine has a different effect depending on the engine type. Moreover, in the engine idle phases on ground or in descent, the type of off-takes can have a direct impact on the idle rate and therefore on the fuel consumed during the mission.

4.2. Addressing the Ground Phases

On a short-medium range aircraft, fuel consumption during the ground phases is not negligible. An APU consumes 100kg/h. If we consider that there is about half an hour's operation between each flight, the consumption is 50kg, i.e. 2% of the fuel used for a Paris-Toulouse flight. The ground power units are often used. By adding one or two power units depending on aircraft size, it could be possible to stop the APU, hence an immediate fuel saving.

Savings can become more significant if electric motors are installed in the aircraft wheels for taxiing on APU power with engines stopped. The power demand is in the range of 100kW and compatible with power generation of the More Electric Aircraft.

4.3. Other Potential Savings

The electrical systems will not increase reliability, however, they should have a positive effect on dispatch thanks to their capacity to anticipate failures, isolate faults and reconfigure networks. A leak on a hydraulic equipment item results in loss of the system and requires a repair action before the next flight. In aeronautical language, the fault is said to be "NOGO".

If an electrical equipment item is defective, it is isolated by its line circuit breaker. Generally, the systems are fault tolerant. The fault is said to be "GO".

The fault "equivalent" to the loss of a hydraulic system is the loss of a busbar whose probability is less by approximately two orders of magnitude. This results in a better overall dispatch reliability of the aircraft.

As regards failure anticipation, monitoring of the electrical parameters associated with system behaviour models will provide a very accurate view of system condition and help in making a decision on whether it is advisable to repair immediately or wait for the best opportunity.

Typically, thanks to reflectometric devices, it is possible to locate an electrical defect on the wiring with one-meter accuracy. Even if these studies are only at the research stage, they show what can be expected from more electric systems.

It is also to be noted that an initial analysis of the life cycle shows that out of the six criteria considered such as the materials used, storage or end of life, the all-electric aircraft is better or at least equivalent to conventional designs.

5. Conclusion

Research is very active and pushed by major actors such as Airbus, Liebherr, Safran, Thales and Zodiac. The European project MOET has permitted a significant step towards the all-electrical aircraft concept, which is pursued in European Clean Sky project. Significant support from the Research laboratories is an essential element considering the extent of the change. This is also a very strong research theme in the United States.

The expected benefits are improved fuel consumption, rationalized onboard systems and improved maintenance for the airlines, however, the performance of the solutions proposed still has to be improved.

Aviation should also benefit from automotive components as the required performance is very similar. Electric technology is a fast changing world.

The all-electric aircraft is technically feasible. Partial solutions are already operational. This is an opportunity to rethink the electrical architectures of aircraft.

The technological rupture induced by the all-electric aircraft is a credible goal for the next generation of aircraft.

About the Author

Etienne Foch
Airbus Operation SAS – M30
316, route de Bayonne
F- 31060 Toulouse Cedex 9
etienne.foch@airbus.com
www.airbus.com

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-359

Transmission in Aircraft on Unique Path WirEs

Sébastien KIM

Abstract. Within the framework of ACARE (Advisory Council for Aeronautics Research in Europe), Safran Engineering Services is working on several projects regarding EWIS (Electrical Wiring Interconnection System) issues. It is presently coordinating the European research project named "TAUPE" (Transmission in Aircraft on Unique Path wirEs), the objectives of which are to reduce the weight of the wiring and to simplify the wiring system as well as its maintenance. The internal Safran work programme's goal is to demonstrate a high rank maturity for two technologies: Power Line Communication (PLC) on the one hand and Power over AFDX (PoAFDX) on the other hand. This research action was launched in 2008. Results obtained are presented here after.

Keywords. Transmission, unique path, power line communication, power over data, wires

1. Context

The aeronautical sector is facing several challenges nowadays regarding its performances and its environmental footprint. In order to address these challenges, several tendencies are being observed, among which:

- The More Composite Aircraft;
- The More (or even All) Electric Aircraft;
- The Integrated Modular Avionics evolutions.

The installed electrical power is increasing with time and programs: from a few tens of kW in the Caravelle for instance, we are today facing around 1MW in the Boeing 787. Those tendencies have several electric issues, for instance:

- Increase in the wires mass;
- Increase in the wires numbers and thus in the required volume to install them;
- Increase in the system complexity.

In order to counterbalance those evolutions, technical solutions shall be found. One of these solutions is to decrease the number of wires used and to simplify the architectures of the systems by merging power and communication networks together using:

- PLC (PowerLine Communication) technology;
- PoD (Power over Data) technology.

Those technologies exist already in the day to day life. Indeed, PLC networks can be deployed at home to provide Internet through the electrical plugs and architecture of the house. At the office, many telephones are plugged to a single data cable providing

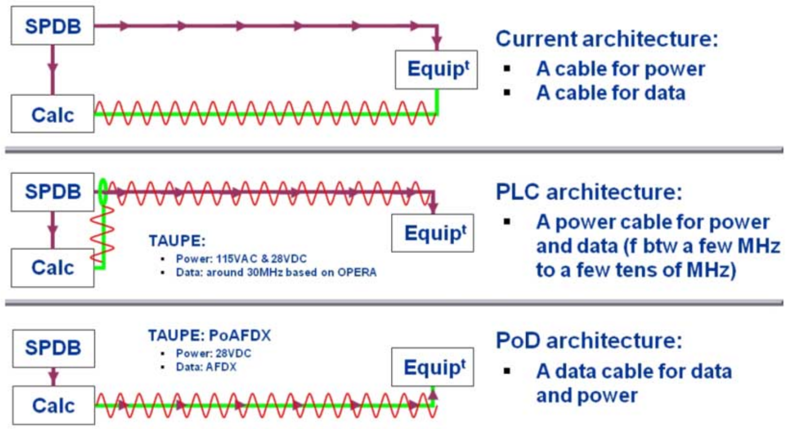


Figure 1. Typical current architecture and evolution towards PLC and PoD implemented architectures.

them with data and power at the same time. However, these technologies are not used today in the aircraft. Indeed, their implementation in this sector raises several issues:

- For PLC technology, the available data rate is dependent on the signal to noise (S/N) ratio. In order to improve this S/N ratio, one can either increase the signal level sent or decrease the noise on the line. However, the authorized level of emission is driven by the avionic standards (DO-160) in order to comply with the conducted and radiated EM requirements. Regarding the noise, it is mainly coming from the other cables routing together in the same harness (cables that might have PLC signal as well). Hence the challenge for PLC technology will be to have enough S/N ratio to transmit the data at a correct rate in the aircraft environment;
- For PoD technology, the challenge is quite different. Indeed, the cable used is a data cable; as a consequence few problems of EM compatibility/ susceptibility are expected. However, the main challenge will be to transmit enough power for the load, taking into account the voltage drop, the thermal constraints and the protection of the power line.

Those technologies and those challenges are the core activities of the European TAUPE (Transmission in Aircraft on Unique Path wirEs) project.

2. PLC, PoD, What Is It?

The definition of a typical architecture and its evolution with the introduction of PLC or PoD technology is presented on Fig. 1. On typical current architectures, equipments are powered by a Power Distribution Box (a Secondary PDB in the example) with a dedicated cable (violet cable) and communicate with a calculator through another dedicated cable (green cable). When PLC technology is implemented, the data cable can be removed and the data is modulated on the power cable. In the TAUPE project, 28VDC and 115VAC networks are used for the power and the data is modulated at around 30MHz, based on the OPERA protocol. On the contrary, when PoD technology is used, the power cable can be removed and the power is just added on the data cable cores. In

Figure 2. TAUPE partners.

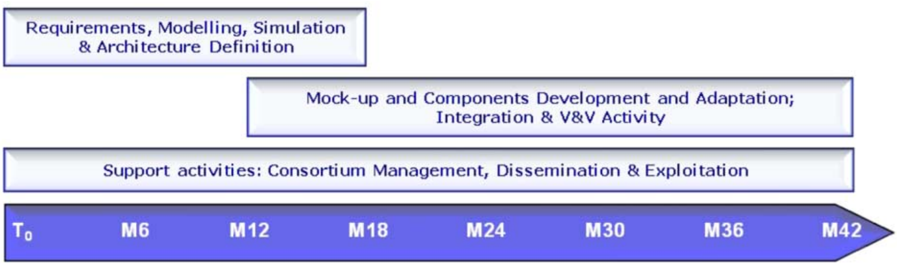


Figure 3. Timeframe of the project.

the TAUPE project, the AFDX network will be used and the power will be added based on the 28VDC network.

3. Framework of the Project

The TAUPE project was launched in September 2008 for a 3.5-year duration. The consortium consists in 17 partners coming from 6 different European countries (France, Germany, Netherlands, Switzerland, Spain and Romania). The 17 partners are presented in Fig. 2. TAUPE is a level 1 project, with a total budget of 5.5M€ funded by the European Commission under the 7th Framework Program. The project is coordinated by Safran Engineering Services (subsidiary of Labinal, SAFRAN Group). The timeframe of the project is also illustrated on Fig. 3. It can be divided into 2 main parts:

- Requirements, Modelling, Simulation & Architecture Definition: this first part lasted 18 months and was dedicated to the expression of the requirements. The objective was to define the targeted architectures, to model and simulate them in order to perform an optimisation. Measurements were also made in order to validate the models and the simulations. Last but not least, the Verification & Validation (V&V) plan was initiated;

Figure 4. Low power bench (Labinal facilities).

- Mock-up and Components Development and Adaptation; Integration & V&V Activity: this second part is really dedicated to the demonstrations in themselves. The objectives are to develop the required components, to integrate the demonstration benches and to perform the V&V test plan in order to assess the performances of the technologies with respect to the requirements identified in the first part.

The main objectives of the project are two-fold: there are global objectives and internal objectives.

The global objectives are to address the ACARE SRA by:

- Reducing the weight;
- Simplifying the cabling maintenance;
- Simplifying the cabling system;
- Making possible a cost effective retrofit;
- Strengthening competitiveness of European stakeholder.

The internal objectives are:

- To demonstrate a Technology Readiness Level (TRL) of 4 (Component and/or breadboard validation in laboratory environment), using:
  - The Cabin Lighting and Communication System (Diehl Aerospace) on a Cabin Mock-up (EADS-IW) for the PLC technology;
  - The Cockpit Display System (Thales Avionics) on the A380 CDS test bench (Thales Avionics) for the PoD technology.

4. Achievements of the First Part

At first, the architectures and aeronautical environment of the current existing applications were described.

Regarding PLC technologies, a modelling/simulation activity was performed. Initial models were used to simplify the system architecture in order to build a "low-power" bench that is representative of the targeted applications in a laboratory environment (Fig. 4). The validation of the models was done using extensive measurements

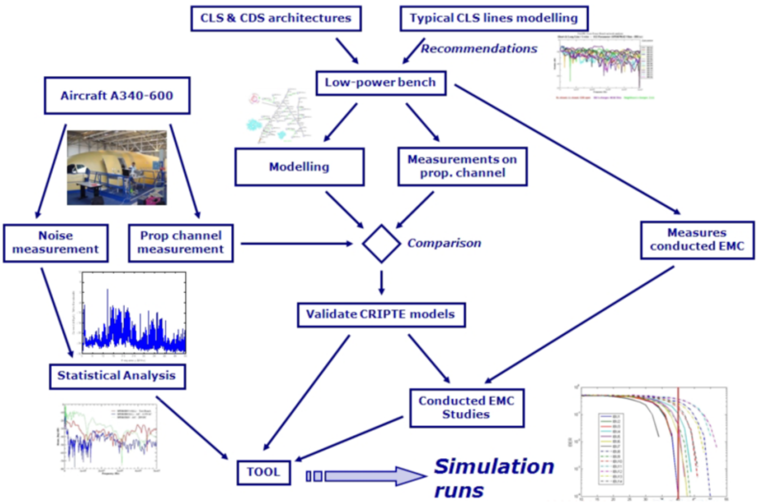


Figure 5. Activities performed during the first part of the project.

on the bench and on a real aircraft (A340). After having validated the models used, extensive simulations were made to better understand the propagation channel, its key drivers and the associated ElectroMagnetic Compatibility (EMC) issues. The measurement campaigns were also used on the noise aspect and its inputs were statistically analysed. The noise, the modelling and the measurement information were used to build a simulation tool to predict the feasibility and performances of a PLC link. Figure 5 illustrates the process that was followed during this first part of the project.

It appeared that with a "common mode" excitation, i.e. between 1 wire and the ground a Bit Error Rate (BER) below 1E-4 for range below 30m and a bit rate below 15 Mbit/s is achievable. Whereas in "differential mode" excitation, i.e. between the 2 conductors of a twisted pair, a BER below 1E-4 for range below 30m and a bit rate of 30 Mbit/s could be achieved (60Mbit/s might even be reached except for the longest lines). Based on those conclusions, the "bifilar" approach was adopted. In terms of mass savings, the first assessment performed showed a 29% saving on the cables mass and 18% on the overall system.

Regarding PoD technologies, PoAFDX was chosen (after discarding the PoCAN). Initially 96VDC was considered but after inquiring further, the 28VDC was technically possible (in terms of voltage drop and thermal behaviour) and was lighter in terms of mass: the first assessment showed a 19% saving on the cables and impacted hardware.

Based on the whole modelling/simulation activities, new architectures were proposed and optimised (PLC will be used on the CLS/CCS system and PoD on the CDS system); requirements for modems and chipset were also produced. Based on those requirements, chipset and modem selection was done and the firmware modified to be optimised and to enable the integration of the chipset with the modem.

Demonstration benches designs have been updated and production of modified or new elements was on-going.

Safety activity and preparative Verification & Validation activities were also performed to prepare the final V&V activity that will end the project.

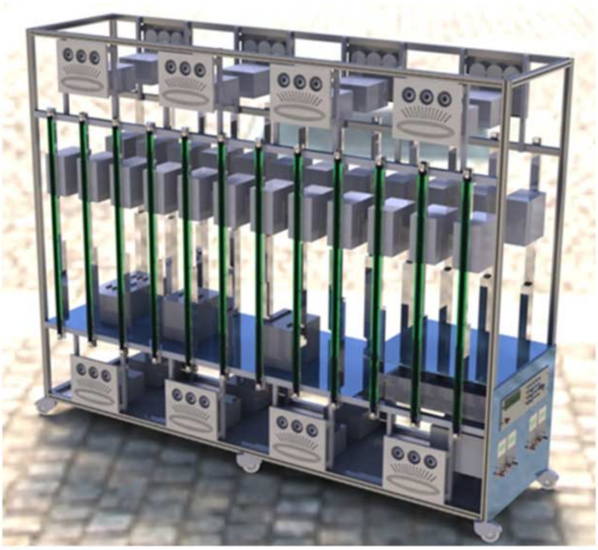


Figure 6. Cabin Mock-up layout.

5. Developments Made in the Second Part and Way Forward

The overall PLC system concept has been elaborated to meet the requirement specifications for:

- System performance for reference applications;
- Applicable EMC standards (DO 160);
- Weight saving requirements;
- Detection of wire fault and/or bad contacts;
- Safety aspects.

Additional hardwares have also been developed to make the demonstration possible. Concerning the Cabin Mock-up, it has been updated, especially in terms of wiring, in order to welcome the technological demonstrations. Figure 6 shows the overall Cabin mock-up layout. Regarding the A380 CDS Bench, it has been modified and the integration tests have already begun.

Last but not least, the detailed planning for V&V has been initiated and the facilities booked.

At the day of the Aerodays 2011 Conference presentation (Madrid 30 March – 1 April 2011), the project was not over yet and activities were still to be performed. On the demonstration side, the Cabin Mock-Up still needed to be integrated. The optimization/adaptation of the chipset/modem to the project requirements and the development of the additional modules were not finished yet. Once the benches would be integrated, integration tests should be performed to assure their availability for the V&V campaign.

On the V&V activity side, the V&V test plan needed to be finalised, the tests on the demonstrators to be performed and the corresponding reports to be written.

6. Conclusion

The expected performances are quite promising after the first part of the project. Those performances are being confirmed by experimentation. A Dissemination Event will also be organised at the end of the project, in February 2012, to present the final results and to draw the corresponding conclusions regarding the applicability of PLC and PoD technologies in the aircraft.

About the Author

Sébastien Kim
R&TD Project Manager
LABINAL/Safran Engineering Services
2, Avenue du Président Roosevelt
31340 Villemur-sur-Tarn
France Tel.: +33 (0)5 62 22 70 27
sebastien.kim@safran-engineering.com
www.safran-engineering.com

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-366

A Technical Vision of Sustainable Commercial Air Transportation in 2030

Alan H. EPSTEIN

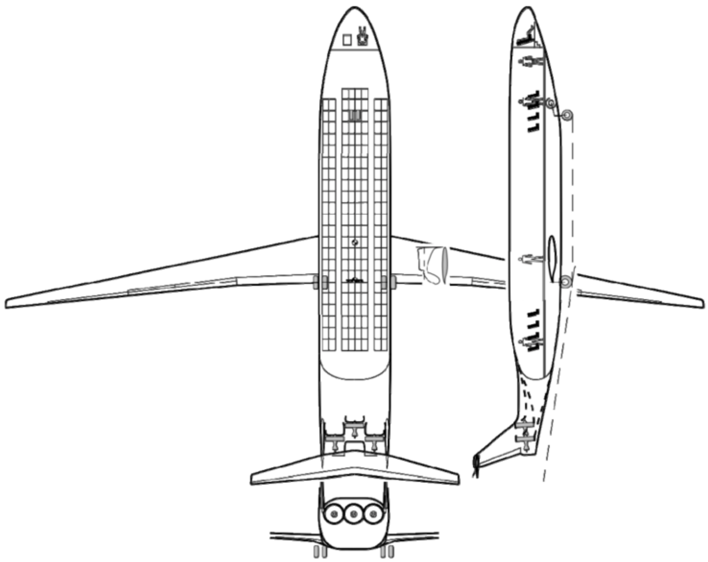
Abstract. In the last few years, concern for climate change coupled with high and uncertain prices for petroleum based fuels has stimulated aerospace R&D around the world. Even without this recent stimulus, over the past 50 years, the fuel per seat km burned by a commercial jet has dropped by over 80%, at compounded rate of about 2% per year since 1970. This tremendous progress has been made without deviating from the fundamental architecture of the Boeing 707, introduced into service in the late 1950s. While modern aircraft are much more refined in their aerodynamics, structures and materials, subsystems and engines, they retain the same tube-fuselage, low-swept wing, and underwing-pylon engine mount configuration introduced over 50 years ago. European ACARE and NASA N+2 goal setters concurred that this rate of fuel burn improvement can continue at least through the end of the next decade if R&D resources are available. Significant gains in noise and NO_X emissions are desired as well. Pratt & Whitney has worked on advanced engines architecture and in conjunction with the Massachusetts Institute of Technology and Aurora Flight Science has examined a wide range of options including aircraft designs, engine designs, enabling technologies, and fuels as part of the NASA N+2 studies [1]. The studies included engine technology, aircraft architectures, and aviation fuels.

Keywords. Sustainable commercial air transportation, new aircraft, new engine architecture, new technologies, future fuels

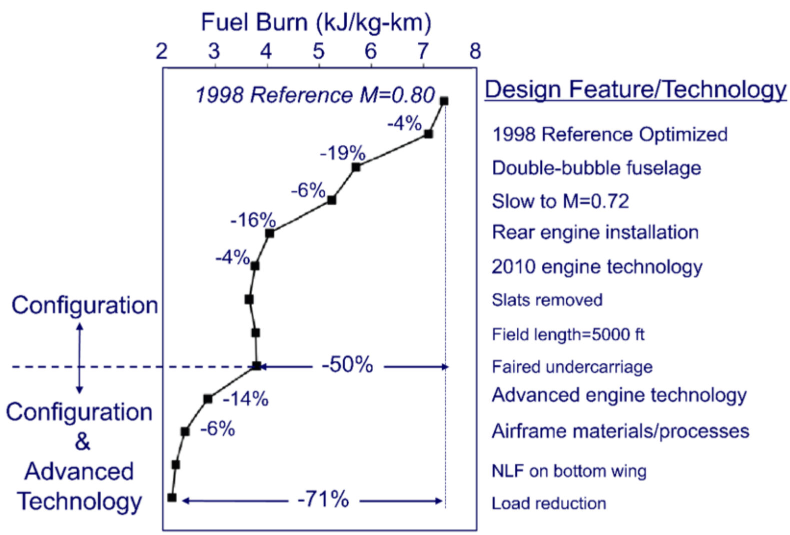
1. A Combination of New Aircraft and Engine Architectures Underpinned with New Technologies

The studies which have been conducted suggest that ACARE and NASA N+2 goals of 70% fuel burn reduction can be met for entry into service by 2030 with a combination of new aircraft and engine architectures underpinned with new technologies. Historically, engine fuel burn has improved at about 1% per year. In order to continue at this rate, both thermal and propulsive efficiencies must improve. Engine thermal efficiencies will improve in much the same manner as before – primarily better materials and cooling technology, increased compression ratio, and improved component performance (although the details of the technologies needed to realize these improvements will evolve).

One such new aircraft architecture aimed at the narrow body segment, called D.8 may reduce fuel burn by about 50% using relatively near term technologies (Fig. 1a). Additional technologies which could be ready by 2030 may enable an additional 20-30% fuel burn reduction. Reaching such an aggressive goal requires many changes and innovations, the most important of which are shown (Fig 1b). The two largest improvements result from an architecture change. The first is so-called double-bubble lifting fuselage which significantly reduces the wing area needed and the overall net drag.



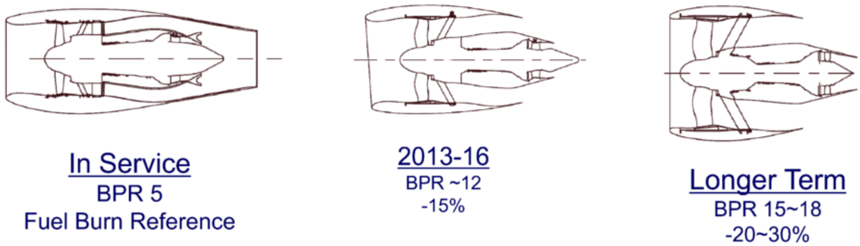
a) 180 Passanger D8



b) Fuel burn improvements delivered by design features and technologies for a 180 passenger D8 configuration

Figure 1.

The second largest improvement stems from mounting the engines at the rear of the fuselage such that their propulsors ingest the top surface boundary layer. This enables the well known wake cancelation effect which reduces drag still further. Together, these the drop the fuel burn by 25% compared to aircraft in service today. Another 6-8% can be realized by re-optimizing the configuration, especially the lifting surfaces for a lower maximum flight speed, M = 0.72~0.75, assuming this is commercially viable. It is to be noticed that in this study, configuration optimization for lower



a) b) c)

Figure 2. An evolution of bypass ratios (BPR) in sustainable engine configurations.

flight speed that minimizes fuel burn, preclude flight at higher Mach numbers. An additional 20+% would come from engine improvements.

Propulsion in this configuration is more highly integrated with the airframe than is common today, which imposes constraints on engine design. In particular, energizing the fuselage boundary layer with the engine propulsors requires (a) that engine propulsors be ducted (precluding open rotors), and (b) that the bypass ratio be sufficiently large that the accumulated low momentum boundary fluid can pass through the bypass duct and not enter the core, where it would decrease thermal efficiency. Numerically, the studies showed that bypass ratios (BPR) of 13:1 or above are needed. The Geared Turbofan™ engines that will be entering service in 2013–2015 have about 12:1 BPR (Fig. 2).

The studies showed that new materials to reduce weight and cooling requirements such as improved polymer matrix composites in the fan module, ceramic matrix composites in the high compressor and turbine, and increased use of metal matrix composites can be important contributors. Improved component efficiencies enable by new materials and manufacturing technologies can also be expected. Taken together, this means that ultra-high bypass ratio, ducted Geared Turbofan™ engines are a key enabling technology.

In addition to reducing fuel burn and therefore CO_2, the improved efficiency combined with advanced combustor technology can reduce NO_X by 70–90% below today's CAEP/6 standard. The change in aircraft architecture combined with quiet, Geared Turbofan engines may reduce cumulative noise by 40 dB. Additional aircraft level noise reduction techniques may be developed by 2030 to reduce the noise level by an additional 20 dB.

In regards to future fuels, the study confirmed that liquid hydrocarbons remain the fuel of choice for minimum fuel burn. Thus, aircraft configuration need not change to accommodate a different fuel. The low density of liquid cryogens such as LH_2 and methane render them a poor choice for high speed aircraft. The recent extension of jet fuel standards to include fuels derived from biomass shows that current jet fuel types need not be fossil based. Progress will now be measured by sustainability of the sources and the net carbon saving of the entire production and distribution process of alternative fuels.

To justify the investment, each all new airplane model must deliver an operating cost advantage of 10~15% over current models, with a concomitant improvement in fuel burn and engine efficiency. The current aircraft configuration, two engines mounted under a low wing, is favored by aircraft designers because it appears to deliver the best value to airline customers at most aircraft sizes. This study implies that by

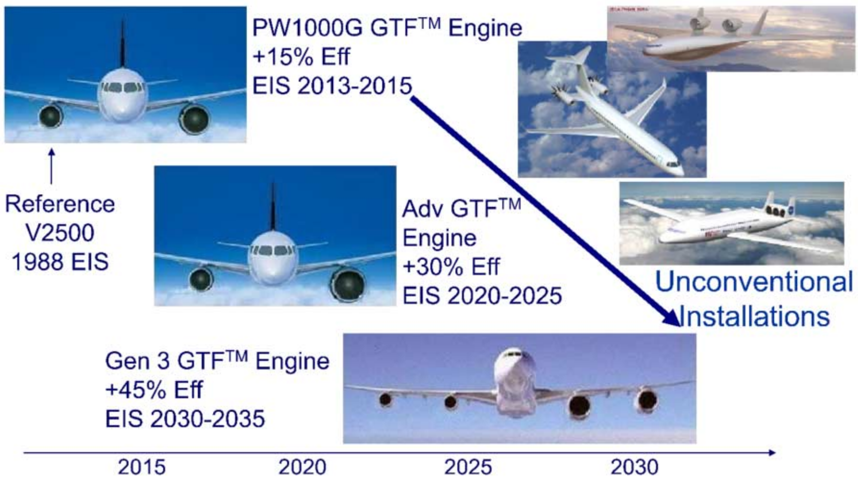


Figure 3. The demands for the increased propulsor area needed to improve fuel burn will force an increased number of engines or all new aircraft configuration by 2030.

2030 new low-wing twins will no longer be able to deliver that value. A new configuration will be needed, driven by the fundamental need to improve sustainability and aircraft economics (Fig. 3).

While many improvements in thermal efficiency can be implemented "under the hood" of an engine, the only way to significantly improve propulsive efficiency and noise at constant thrust is to reduce the propulsor exhaust velocity and therefore its pressure ratio. This means that propulsor area must increase, which usually means the diameter must increase. At some diameter, the current low-wing, twin-engine configuration is no longer viable; the engines simply do not fit. This point may be reached by the middle or end of the next decade. If a low wing is desired, then adding more engines could provide the area needed. Certainly aircraft can be viable with four engines (A380, B-747) or even eight (B-52). Alternate engine placements offer another solution, above the wing (Honda Jet), at the rear (DC-9, Mercure, Trident), above the fuselage (D8, blended wing bodies) are all possibilities.

Whatever the solutions adopted, the next two decades will be an exciting one for aviation and a rewarding one for the world's economies as technology is developed to enable increasing sustainable and affordable commercial aviation.

References

[1] E.M. Greitzer et al., "N+3 Aircraft Concept Designs and Table Studies, Final Report", NASA CR 2010-216794, 2010.

About the Author

Alan H. Epstein
Vice President, Technology and Environment
Pratt & Whitney, East Hartford, CT 06108, USA
Tel.:+1 (860) 565-7774
alan.epstein@pw.utc.com

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-370

CREATE – A European Initiative for Stimulating Ideas and Incubating Upstream Research Projects in Air Transport

Romain MÜLLER, Patricia PELFRÈNE, Adriaan de GRAAFF, Dieter SCHMITT, Gernot STENZ, Guy GADIOT, Gerben KLEIN LEBBINK, Chris BURTON, Surinder KOONER, John KIMBER, Trevor TRUMAN and Peter PHLEPS

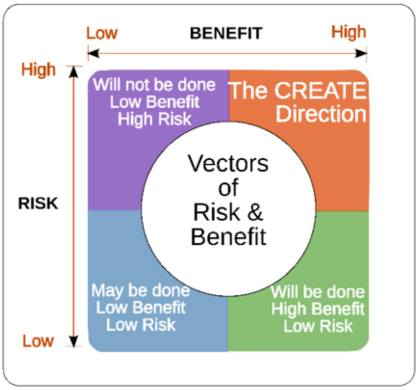
Abstract. The CREATE project was initiated following an earlier path-finding project called "Out of the Box" [2]. The rationale for Out of the Box was that the generation of ideas for radically changed concepts and technologies for the future Air Transport system needs to be stimulated and ideas need to be collected on a European scale. The CREATE project studied and tested a process that includes all the steps necessary to bring these ideas for radical changes in air transport into actual research.

Keywords. Stimulating ideas, upstream research projects, creative workshops

1. Introduction

The CREATE process is focused on step changes in aviation. It does not seek to address all kinds of research but a relatively narrow, important part of the whole: the high risk research with potentially high benefits in the longer term future. It does not displace any more incremental routes to innovation but augments them.

It aims to stimulate step changes to the aviation system with particular attention to those that are cross-sector, transformational in their implications, and is concerned with the long-term future aviation system.



The project showed that high benefit and innovations of high risk effectively have no mechanism by which they can be studied for potential use in the long term future. The project concluded that a new process is required – one which will address this particular set of innovations and allow them to be studied and tested for validity as potential elements in a future air transport system.

2. The CREATE Process

The CREATE project identified process mechanisms to encourage concepts and ideas to be put forward, by providing assistance for their development and extension, by allowing additional data and constructive views to be brought to their support, by transforming ideas into research proposals that would be assessed independently and to incubate the idea until it is mature enough to compete with other research proposals that aim at more incremental improvements.

Most novel ideas face hostility. Given the radical nature of some of the ideas it is likely that they would face premature and negative decisions. To overcome this, the key process element is seen to be an “incubation” stage. This is comparable to a nursery for children; the child is allowed to grow in a protected environment, to acquire greater knowledge free of demands for performance. Eventually, of course, the child must meet the demands for performance, competition and choice but the period in the nursery equips them to meet these forces. Incubation as a concept is a parallel to this. It will provide a protected environment where the viability of an idea can be studied, expanded and developed to the level where it can provide comparable credibility to established evolutionary ideas. In one respect, however, the incubation stage is unlike a nursery. If the work to develop the idea shows that it cannot work then the incubation should be stopped.

The CREATE project set out to define, test by demonstration and refine a CREATE process except that it was never the intention to carry out a trial of the incubation process given the cost and length of time that this would take.

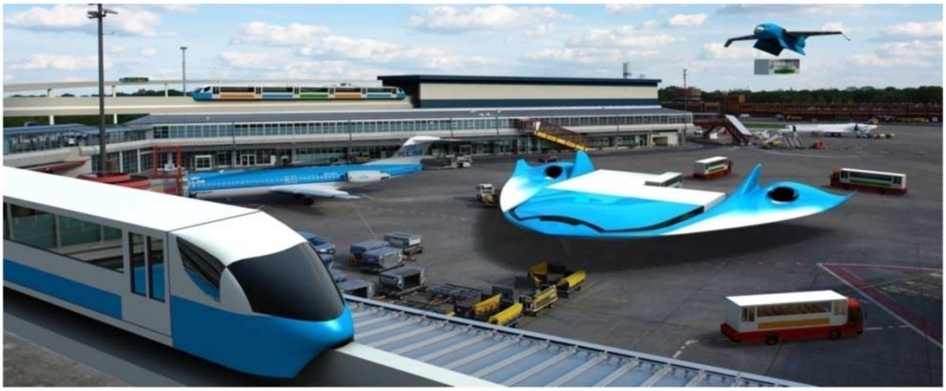
Five mechanisms were tested during the project: Creative Workshops, an Innopedia web-based discussion platform, Technology Watch to identify new technological developments in other domains, the IDEA Portal to assist originators to develop their ideas and the Assessment process for impartial evaluation.

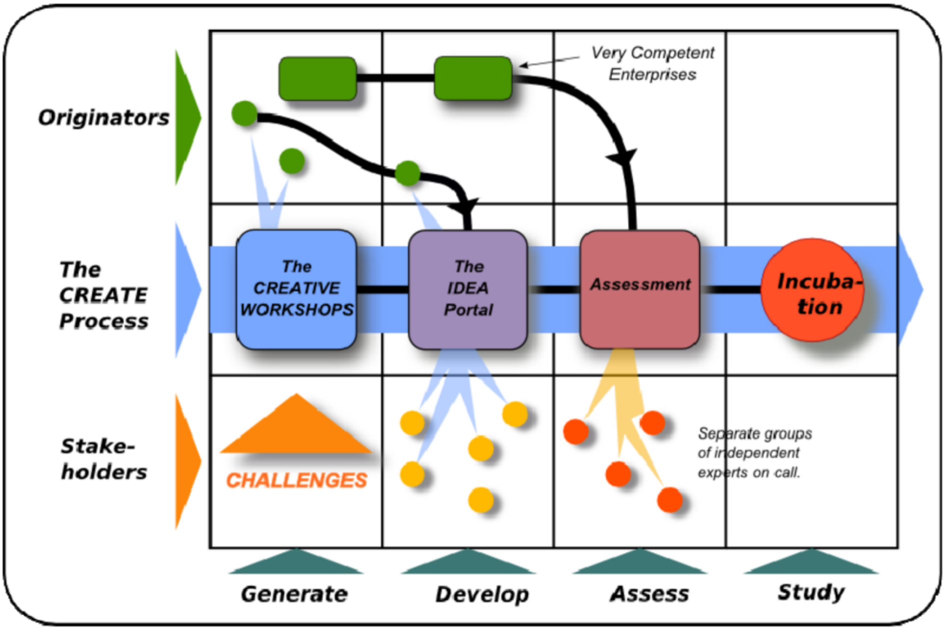
The workshop resulted in a large number of creative ideas (more than 130). As usual only a limited number of ideas were deemed to be worthwhile to follow up. A limited number of ideas were used to test some of the CREATE other process elements.

The need for the IDEA Portal to further develop initial ideas into a research proposal was well established. During this activity several elements of ideas selected were further developed.

A new set of evaluation criteria was developed for the proposal assessment phase. These criteria were tested in a workshop and found to be suitable.

In two areas it was concluded that the elements should not be further developed: the establishment of the wiki-based Innopedia and a Technology Watch. The work done on Innopedia and Technology Watch (TW) pressed hard to develop processes that would realize the aspiration of the project for them. In the case of Innopedia the process was exhaustively tested but failed to demonstrate that enough people from around the aviation community were sufficiently interested in the topics of step change innovation





to sustain the process at the level hoped. Technology Watch was originally seen as an alert based system that would inform interested groups within aviation of technology developments of potential being adopted in other domains. This did not prove to be economically viable. The use of Technology Watch for providing specific search results is recommended as commercial activity for which systems already exist. The Commission may, however, want to assist SMEs to use these commercial TW instruments.

In the area of incubation no test has been carried out, as this was beyond the CREATE project remits. However, the conditions for incubation contracts and the management of incubation have been studied in the project. CREATE recommends to facilitate feasibility studies during the incubation phase of a research project.

3. Conclusions and Recommendations of the Project

The CREATE process is to be established as a stable, long-term mechanism that can satisfactorily address the gap in the innovation chain.

The principal steps that need to be secured before this stability can be achieved are:

- Establishing the support and participation of the aviation stakeholders;
- Securing an enduring mechanism for funding the process.

If these can be addressed successfully then, along with the process development that has been the subject of the CREATE project, a stable process can be established as a long term mechanism for providing, over time, a portfolio of innovative, important, and cross sector ideas which are needed with greater force and with greater speed as the challenges facing the world develop.

Each of the steps – Creative Workshops, the IDEA Portal, and Assessment – were developed and defined for potential use and are recommended as part of the process for implementation.

It has initial stakeholder support, a process for placing incubation contracts has been developed, the provision of creative, developed and rigorously reviewed ideas has been proven through tests and the mechanisms for introducing this into use and accumulating a portfolio of incubated ideas for the future of aviation have been identified [1].

Two key issues remain to be determined: the provision of the funding stream for incubation contracts and the mechanisms by which the European Commission and the Member States wish this to be applied to incubation contracts.

The conclusions of the CREATE project are clear on these two issues.

a) The objective of an implemented CREATE based innovation mechanism should be to accumulate, over a 10-year period, a portfolio of incubated ideas addressing major innovation schemes for air transport;
b) Incubation contracts should be funded with 95% public funding for the feasibility studies in incubation phase;
c) This funding should be found from within the European Commission research budget and it is recommended that implementation of the CREATE process should begin in FP7;
d) The mechanisms recommended for stimulating, extending and assessing ideas and monitoring the progress of their incubation contracts may be carried out by the European Commission or by sub-contracting or by a mixture of both approaches.

Estimates of the cost of operating the total CREATE Process including incubation (€ 3 million annually) have also been compiled. The cost is remarkably small when set against the potential importance of the ideas that may emerge from it – only about € 3.5 Million per annum in total. Work on the early stages of an idea is not expensive and, in most cases, feasibility studies will not require any costly test items or facilities to be built. The majority of the work will be in developing comprehensive, multidimensional (economic, technical, operational, regulatory, environmental and social) models and describing each idea and its implications. This will, in most cases be sufficient to take the idea forward to TRL 1 or 2 and, if the idea still appears promising, allow technology development to be taken forward thereafter with confidence.

Given the work done during the CREATE project the specific steps recommended by the CREATE project team for the implementation of this important innovation stimulus were as follows:

a) Make a start on inviting submissions for incubation funding within FP 7 using the FET-Open scheme as a model;
b) Support the total CREATE process by European funding at about €3.5 million per annum;
c) Decide how the operational management of the process (described here as the CREATE process) should be managed, entirely by the European Commission or with some functions carried out under contract to them;
d) Develop the further extension of the scheme for Horizon 2020 using the model of management decided upon and inviting submissions through an annual series of carefully constructed open calls (95% funding and a two stage evaluation);
e) In conjunction with the planned report for a Vision 2050 to launch an aviation community publicity campaign to inform stakeholders in the future of air transport on how proposals for this closely defined area of innovation will be received, used and integrated into the research programme.

4. Recent Developments

The European Commission has accepted the need to implement a CREATE type of process and intends to allocate € 10 million in total for incubation during the last two calls of Framework Programme 7 theme Transport (including aeronautics). These projects will be known as Level 0 projects.

References

[1] CREATE, Creating innovative air transport technologies for Europe, Final Report of the CREATE project (Grant Agreement 211512) of FP7 under designation “AAT-2007-7-4: Stimulating radical technological changes”, ASD, Brussels, Belgium, October 2010.
[2] A. de Graaff and T. Truman, Out of the Box – Ideas about the future of air transport (Part 2), European Commission, November 2007.

About the Authors

Romain Muller and Patricia Pelfrène
ASD
Tervuren Avenue, 270
B-1150 Brussels (Belgium)
patricia.pelfrene@asd-europe.org www.asd-europe.org

Drs Adriaan de Graaff
AD Cuenta B.V.
adgraaf@hetnet.nl
www.Adcuenta.com

Dieter Schmitt
ARTS

Gernot Stenz
Bauhaus Luftfahrt

Guy Gadiot and Gerben Klein Lebbink
NL Agency

Chris Burton, Surinder Kooner and john Kimber
QinetiQ

Trevor Truman
Consultant

Peter Phleps
TU Munich

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-376

Small Aircraft Transport as a New Component of the European Air Transport System

Krzysztof PIWEK

Abstract. A visionary European Transport system should be based on an environmentally sustainable, cost efficient, seamless and co-modal passenger friendly system aiming at ensuring mobility and cohesion for the Europeans. The challenge is to create a new component of European transport by wider use of small aircraft using regional airports, to enable access to more communities in less time. The FP6 "EPATS (European Personal Air Transport System) Study" showed that 7% of the future car travel in 2020 could be shifted to Small Aircraft Transport Systems (SATS).The FP7 study called "SAT – Roadmap" will set out a technology roadmap for the research actions necessary to implement such a transport system.

Keywords. Small aircraft, small airports, regional airports, personal air transport

1. A Vision of the European Transport System

Different scenarios can be envisaged for the future European Transport System depending on many factors (social needs, economy, fossil oil price and availability, environmental concerns, climate change, political choices and stability). A possible visionary European Transport System should be based on an environmentally sustainable, cost efficient, safe, seamless and co-modal passenger friendly system aiming to ensure mobility and cohesion for the European citizens while enabling economic growth.

"More people and greater economic affluence mean more mobility and more transport. Some studies suggest that the number of cars in the world will increase from around 700 million today to more than 3 billion in 2050, creating serious sustainability problems unless there is a transition towards lower and zero-emission vehicles and a different concept of mobility is introduced in an environmentally friendly way". According Communication from the European Commission: "A sustainable future for transport: towards an integrated, technology-led and user friendly system" Brussels, 17 June 2009 [1].

One future element of such an advanced transport system will be transportation using small aircraft and small/regional airports. This new transport mode will enable fast travel in areas of Europe where high speed trains or traditional airline connections are unavailable and will alleviate road congestion problems in a customer – and environmentally friendly way.

"General and business aviation complements regular air transport performed by commercial airlines and thus provides specific social and economic benefits such as increasing the mobility of citizens, the productivity of businesses and regional cohesion". According European Parliament Resolution of 3 Feb 2009 on an Agenda for Sustainable Future in General and Business Aviation [2].

2. What is the Small Aircraft Transport System – SATS?

The challenge is to create a new mode of European transport by wider use of small aircraft using small and regional airports, enabling access to more communities in less time.

SATS aims at the segment of the transport market that is not served by scheduled air transport or high speed trains, which today results in a substantial need for road travel for short to medium distances, to answer the specific needs of business and other users The small aircraft transport mode can fill a gap, which exists between Surface Transport and regular mass Air Transport.

The main idea is to shift a part of medium/long distance passenger car trips to small aircraft to improve the efficiency of passenger transport, relieve the congestion on roads and thus reduce the environmental impact. Taking into account the travel cost and the value of time saved by air travel, SATS will offer an attractive alternative to travel by car for distances greater than 200 kilometers.

The Small Aircraft Transport responds to trends in society that are serious challenges for transport system i.e. spending less time in travel and creating better conditions for traveling, while meeting the following conditions:

- Use less energy;
- Increase safety and security;
- Reduce pollution;
- Reduce costs;
- Exploit more efficiently the exis-ting infrastructure;
- Deploy intelligent transport system to achieve efficiency and easy of services reservations.

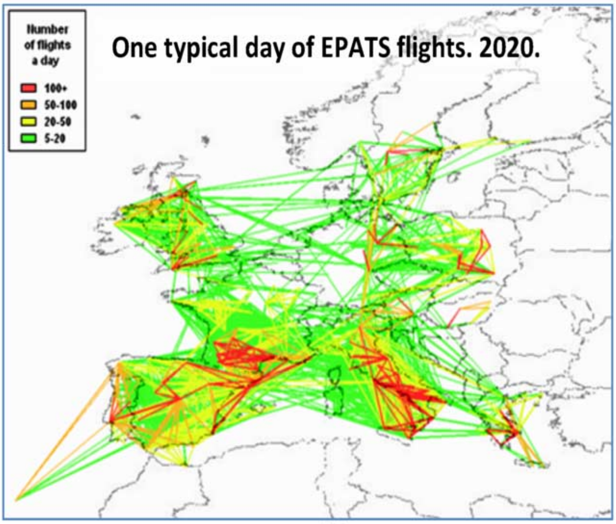
The Small Aircraft Transport System will use small 4 to 19 seater aircraft, single pilot crew and automated control & guidance, flying IFR operations, with propulsion systems that are tailored to the missions, using the network of regional airports, supported by appropriate ATM-ATC systems and an ICT infrastructure (Information and Communication Technology) to provide an easy reservation system and per-seat on-demand air travel and enable more effective operational and administrative procedures [3,4,13,14,20].

The FP6 project EPATS-STUDY (European Personal Air Transportation System – Study) showed that the currently available airport infrastructure (2570 airports and airfields in Europe) is sufficient to provide easy access to all European communities. About 60% of the European population is living within a distance of 20 kilometers from the nearest regional airport, whilst for 95% of the European population the nearest regional airport is within a distance of less than 40 kilometers.

The existing airport infrastructure will be sufficient (SATS will use satellite CNS and satellite based landing aids).

3. Affordability

Calculations show that small aircraft transportation is cost effective compared to road traffic over distances greater than 200 km. Using modern mass-produced small aircraft based on advanced technology and an intelligent transport business model, SATS will



EUROCONTROL, D3.1 EPATS ATM, 2008 [3]

be affordable, and once full maturity is reached, costs will be similar or less than car travel [4,14,15].

4. Impact on the Environment

The environment remains the main policy area where further improvements are necessary.

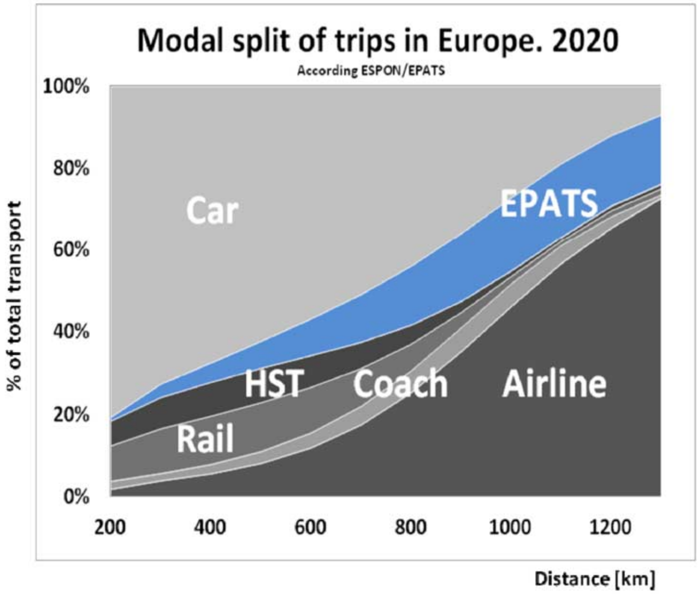
The impact of different mode of transport on environment is usually assessed by costs externalities measurements. Many researches were made to compare road and air transport. In all cases, the impact of air transport on the environment is much friendly than in the case of road transport; it concerns noise pollution, local air pollution, traffic congestion, crash and others [13]. According to European Environmental Agency Road transport – the largest share of both passenger and freight mobility volumes – is also the largest contributor to total external costs. Road transport modes also have relatively higher average costs per passenger-kilometer and tonne-kilometre than other modes [21].

As fuel consumption per passenger/km is lower for aircraft, than the emission of harmful gases and particles per passenger kilometer are less than in cars. Implementation of the Clean Sky will also benefit SATS [1,2,15].

In relation to 1 passenger-km road transport needs many times more land than the air transport [16]. Given the use of existing airports SATS implementation does not require new land.

The noise level of SATS aircraft is already regulated. It is expected that current noise levels can be lowered significantly in future thanks to new technologies and procedures.

Although small piston aircraft use mainly 100LL aviation fuel now, there is a need for replacing Avgas by more friendly to environment, such as unleaded, or biofuel.



5. The Potential Market of Sats

EPATS-STUDY showed that small aircraft transportation is beneficial for business travel in Europe, especially in southern France, Spain, Portugal and Italy, as well as in Eastern Europe [8], adding a new relevant market towards the current business aviation market which is currently more mature between London and Milano.

The EPATS project showed that 7% (96 billon pas.km) of the future car travel (by means of affordable operating costs) in 2020 could be shifted to SATS. This would require a fleet of 89 000 small aircraft (4 to 19 seats), and generate up to 43 million flights per year [3,4,10,11].

The project participants expect that further studies will address interregional mobility in the EU, to better identify passenger flows to better estimate the future demand for small aircraft transportation.

6. Business Aspect

The business cases are generated by straight forward choices, but have complex operational characteristics. Operational characteristics and elements of the business cases include:

- Totally on-demand: the passenger is free to choose the final airport destination and the flight time. He always flies without other non-related passengers;
- Semi on-demand: the passenger is bounded in his departure and destination airport choice, but is able to choose its own flight time;
- Per seat on-demand (net-centric case): the passenger is free to decide his departure and destination airport; other non-related passengers may accompany the original passenger to the same destination. Consequentially the passenger

can choose a flight time interval for departure, whereas the operator decides the ultimate intermediate departure time of all passengers. The higher the interval the lower the charter price. Passengers are free to choose different aircraft type according to their demands.

The SATS should operate in the frame of centralised Information and Communication Technology system. ICT solutions will be developed to support better management and integration of transport flows. The structure of the SATS network, planning and service management are aimed at reducing empty flights legs, increasing fleet effectiveness and fuel efficiency, to minimize transportation costs [4,13,14].

7. Safety

Using professional pilots for small transport aircraft operating (both under Parts 91 and 135 of the FAR or EU OPS) SATS will have a far lower accident rate than road transport. The challenge to SATS is to reach safety levels similar to those of current commercial air transport. Improved small aircraft will be based on new technologies that facilitates pilot situation awareness and flying in poor weather, which will help to reach the projected safety levels. Additionally the small aircraft will be supported by new training systems [7].

8. Aircraft Pilot Issues

Using small aircraft means that the pilot costs will have to be shared by a lower number of passengers so, it is crucial to reduce the crew to one pilot, replacing the second by automatic system. SATS will be characterized by efficient pilot management, complying with the rules addressing flight time limitations and required rest periods.

9. The Technology Roadmap

The 7th FP SAT-Roadmap CSA project will set out a technology roadmap projecting the necessary research activities for the implementation and maintenance of SATS in Europe. Technology challenges which will receive extra attention are the aircraft and propulsion efficiency, all weather operations, single pilot operations, noise and emission reduction, safety and security, cabin comfort as well as net-centric IT systems to support different business models. SATS development should be linked to SESAR ensuring compatibility with the SWIM environment of SESAR. Additionally the roadmap will also address future regulation necessary to fulfill the pre-defined set of requirements.

The following topics will be addressed:

1. High Level System Requirements. This relates to Airports – ATM/ATC – Net-Centric Management Centre – SATS Aircraft Family – Service – Environment;
2. The Business Model. To develop affordable and suitable business model for SATS;

3. Advanced ICT. To develop Information and Communication Technologies for the SATS network with the purpose of the system to work on the basis of SESAR's System Wide Information Management (SWIM), integrating SATS aircraft into high volume airspace operations. Eventually Airports can operate with virtual control towers;
4. Resistance to weather hazards. To develop methods and approaches to assure reliable and safe flight operations during poor weather conditions and perform landings at minimally equipped airports;
5. Single-pilot ability. To develop means to safely replace the second pilot using fail safe systems and more automation (using the results of the Sofia, P-Plane and others projects);
6. Efficient Systems and Propulsion for Small Aircraft through dedicated R&TD;
7. Small-Size Aircraft Configurations. Dedicated R&D on new types of aircraft that should constitute the mainstay of SATS (based on CESAR, ESPOSA, Clean Sky, SESAR, EPATS and others);
8. Friendly Legal Environment. Review and update of EASA regulation to provide differentiation of regulations affecting different categories of undertakings and airspace users. Current regulations intended to govern the operation of highly complex commercial aircraft place a disproportionate financial and regulatory burden on operators of small aircraft, therefore, one-size-fits-all regulatory approaches and the uniform enforcement of rules across different aviation sectors have proven inappropriate;
9. Comfort and others.

10. Next Steps

The Resolution by the European Parliament from February 3rd 2009, emphasized the relevance of SATS and the importance of supporting the existing, competitive capabilities which will enable SATS and encouraged the development of innovative aircraft in the European Member States.

It is highly appropriate that policy makers and stakeholders recognize the potential of this new mode of transport and support appropriate actions to develop such a system to its full potential.

Legal Notice

SAT-Rdmp support action is co-funded under the EU's 7 Framework Programme. The views expressed in this publication are the sole responsibility of the authors and do not necessarily reflect the views of the European Commission.

References

[1] Communication from the European Commission. A sustainable future for transport: towards an integrated, technology-led and user friendly system. EC 2009.
[2] European Parliament Resolution of 3 Feb 2009 on an Agenda for Sustainable Future in General and Business Aviation. European Parliament 2009.

[3] D3.1 EPATS ATM General requirements & related issues to be solved. EPATS Consortium – EUROCONTROL 2008.
[4] D5.2 EPATS Roadmap. EPATS Consortium 2008.
[5] System Transportu Małymi Samolotami (STMS) w Polsce. R2.1 Analiza porównawcza parametrów transportowych i oddziaływania na otoczenie pojazdów lądowych i statków powietrznych. (Small Air Transport System in Poland. Transport and environmental performances of car and small aircraft comparison). Instytut Lotnictwa 2009.
[6] STMS. UR2.1.1 Analiza porównawcza czasu i kosztów podróży służbowej samochodem i samolotem osobowym – Przykład obliczeń. Instytut Lotnictwa 2009.
[7] EPATS D1.1 Report on European Business & Personal Aviation Database and Findings. Chapter 4 Total and fatal accidents rate by aircraft type and Operators. EPATS Consortium 2007.
[8] EPATS T1.2 Airports and Facilities Data Base. EPATS Consortium 2007.
[9] ESPON European Spatial Planning Observation Network, www.espon.eu.
[10] EPATS D2.1 Potential transfer of passenger demand to personal aviation by 2020. EPATS Consortium 2008.
[11] EPATS T2.2.1 Synthesis of the EPATS estimation method and results. EPATS Consortium 2008.
[12] EPATS T5.3 Small Aircraft Requirements & Potential Demand. EPATS Consortium 2008.
[13] Koncepcja funkcjonowania Systemu Transportu Małymi Samolotami w Polsce (The concept of SATS functioning in Poland). Institute of Aviation 2009.
[14] Intelligent Personalized Air Transportation System A. Baron – IPATS. Transactions of the Institute of Aviation Scientific Quarterly 3/2010.
[15] EPATS D4.2 Operating Costs Analysis Report. EPATS Consortium 2008.
[16] Air Transport Efficiency and its Measures. Transactions of the Institute of Aviation Scientific Quarterly 3/2010.
[17] Annual Energy Outlook 2006 with Projection to 2030.
[18] Analiza ekologii Systemu Transportu małymi Samolotami (STMS). Etap 1. Karol Ekert. (SATS Ecological analysis). Institute of Aviation 2009.
[19] Evaluation of the air transport efficiency definitions and their impact on the European Personal Air Transportation System development. Jozsef Rohacs. Transactions of the Institute of Aviation Scientific Quarterly 3/2010.
[20] The Challenge of mobility in Europe. A. Baron, M. Mączka, K. Piwek. Transactions of the Institute of Aviation Scientific Quarterly 3/2010.
[21] European Environment Agency – TERM 2002 25 EU – External Costs of Transport.

About the Author

Krzysztof Piwek
EPATS & SAT – Rdmp Project Coordinator
Instytut Lotnictwa (Institute of Aviation), al.
Krakowska 110/114
02-256 Warsaw (Poland)
Tel.: +48 22 868 56 81
khp@ilot.edu.pl

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-383

Novel Tiltrotor Concepts – An Overview of the "NICETRIP" Project

Alessandro STABELLINI

Abstract. During the last ten years, Tilt Rotor research in Europe has had a significant boost. In October 2006, a new project started: "NICETRIP" (Novel Innovative Competitive Effective Tilt Rotor Integrated Project). The latter, coordinated by AgustaWestland, is still running. Its main objectives are to integrate the results of the previous technological studies and to validate the full feasibility of the future European Tilt Rotor "ERICA".

Keywords. Tilt-rotor, rotorcraft, enhanced rotorcraft

1. Historical Background

Between 2001 and 2006 six EU funded projects dedicated to studies on a number of critical technologies were launched. These studies were dedicated to the definition, evaluation, and validation of new technologies to be developed for and integrated into the European Second Generation Tilt Rotor, ERICA (Enhanced Rotorcraft Innovative Concept Achievement) the concept of which was developed by AgustaWestland, at the beginning of the year 2000, with the aim of filling the gap that existed between the US and European Industries in this technology area:

- RHILP (handling qualities);
- TILTAERO (aerodynamic interactions);
- ADYN (dynamics and noise);
- DART (rotor hub design and testing);
- TRISYD (drive system design and testing);
- ACT-TILT (flight control system).

At the end of the above studies, in October 2006, NICETRIP (Novel Innovative Competitive Effective Tilt Rotor Integrated Project) started; a research program funded by the European Union under FP6. The project, which is still running, is coordinated by AgustaWestland with the main objectives of integrating the results of the previous technological studies and of validating the full feasibility of the future European Tilt Rotor, ERICA. The organisation and resources proposed to achieve the project objectives include a 54 month work plan made of 7 Work Packages and a consortium of 29 participants, fully representing the required skills and capabilities.

2. The "ERICA" Concept

The proposed ERICA concept (Fig. 1), in its basic version, is a 12 tonne, dual use, multipurpose un-conventional Tilt Rotor aircraft, for the transportation of passengers or

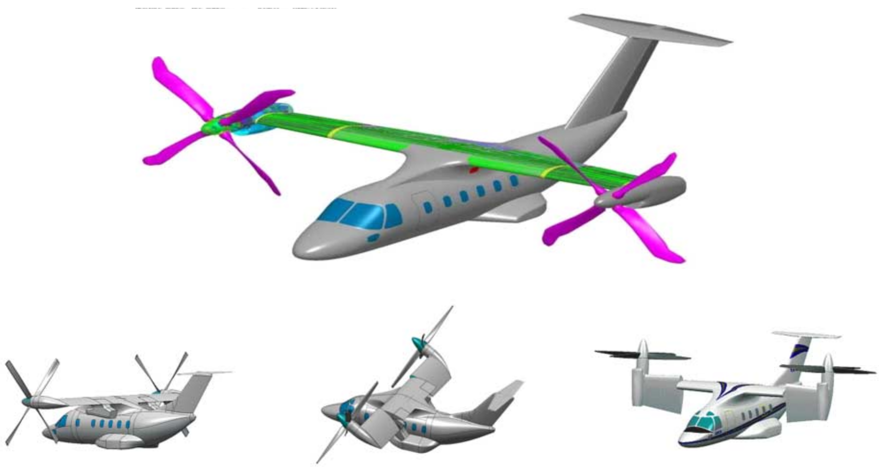


Figure 1. The ERICA concept.

cargo. Its scalable architecture is fully tailored to accomplish all the emerging requirements in the medium-large Tilt Rotor market segment (19–30 pax). Compared to existing Tilt Rotor configurations, the ERICA architecture features the tilting of the outboard portions of the wing independently of the nacelle to improve the hover efficiency and optimisation of the angle of attack of the outer part of the wing according to flight condition. The latter is undertaken during takeoff and landing according to the speed of the aircraft and the wake of the rotor in order to reduce, the required runway length, to minimise buffeting and to increase the efficiency and comfort during the conversion from rotor to wing borne flight. Another notable characteristic of the ERICA configuration is its ability to take-off and land in aircraft mode which is made possible by the reduced diameter of the rotors. The advanced aerodynamic design of the rotors through their un-conventional shaping and solidity factor guarantees high stall margins in the low-speed regime. This coupled with an unconventional continuous structure to effect nacelle rotation assures the lowest weight and higher standards of performance and safety compared to previous concepts.

3. Progress Status

At the current stage of the NICETRIP project, all the design studies have been completed, the aircraft general architecture has been defined and the aircraft specification has been frozen.

In particular the engineering activities relevant to the definition of the vehicle architecture have been successfully completed: conceptual design of the principal systems and dynamic components; validation of analytical tools, weight estimation, performance estimation, flight mechanics evaluation (HQ); loads evaluation and the aircraft aerodynamic and dynamic assessment.

The definition of the major aircraft subsystems has also been completed and includes the preliminary structural design of the fuselage, wing and nacelles, the detailed design of rotor hub, blades and transmission and the preliminary design of the flight controls, hydraulic, electrical and fuel systems.

With regard to the testing activities, an aerodynamic test campaign (Force Model) was carried out in 2008 in the Politecnico of Milan wind tunnel on a 1:8 scale aircraft model. During the next months a test activity on an air intake model will be completed in the wind tunnel at the University of Liege. To enhance safety, a lubrication test and a functional test on a full scale prop-rotor gearbox were performed in April 2011 at the AgustaWestland facilities. A further aerodynamic test campaign is planned in 2012, in the DNW and ONERA wind tunnels. These tests will involve a dedicated 1:5 scale full-span, fully actuated and powered model that has been designed and manufactured by the Dutch National Aerospace Laboratory NLR.

Within the activities dedicated to the introduction of Tilt Rotors in the Air Traffic Management system, a real time simulation in a realistic scenario was conducted in February 2010. This activity connected SICTA facilities with the flight simulators in Eurocopter, NLR and University of Liverpool.

The NICETRIP Project is planned to be complete by December 2012.

4. What Next?

Following conclusion of the above described activities and based on the experience and the knowledge acquired during the last ten years the feasibility and the compliance to the design specification of the ERICA concept shall be considered demonstrated. The next step will then be the completion of the detailed design of some of the key subsystems, their integration at aircraft level and the launch of the complete design and manufacturing of a demonstrator aircraft.

This will, of course, involve a significant effort both in terms of skills and funding and to be successful should be sustained in a joint programme by the major European Aeronautical and High Technology Industries. In other words, to exploit the significant effort and competences acquired within the research activities centred on the ERICA concept, a full flight demonstration program would be envisaged as a natural continuation of the project.

About the Author

Alessandro Stabellini
NICETRIP Project Manager
AgustaWestland
Via G. Agusta, 520
21017 Cascina Costa (Italy)
alessandro.stabellini@agustawestland.com
www.agustawestland.com

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-386

Future High Altitude High Speed Transport Concepts

Johan STEELANT

Abstract. Pioneering the aviation for the second half of the century is a theme which the European Commission is actively supporting since the FP6 and continued doing so within the FP7. Several activities were initiated by ESA in this field which are related to hypersonic cruisers, i.e. LAPCAT [1] and ATLLAS [2] or to suborbital flights, i.e. FLACON [3] and FAST20xx [4] These projects are co-funded by the EC and a large group of about 30 different partners from industries, SMEs, research institutions and academia. Though these activities are mainly technology driven programs, the specifications and requirements for the research and development are driven by conceptual studies on hypersonic and suborbital vehicles. Different hypersonic cruiser concepts have been devised so far for different cruise velocities ranging from Mach 3 to 8 while maximizing the range. Antipodal ranges such as Brussels to Sydney seem feasible but more detailed studies are now required along with flight experiments. For suborbital flights, concepts are laid out leaving the atmosphere and providing a view to earth from space, without going into orbit but still providing a wide variety of potential ranges.

Keywords. High-speed cruiser, suborbital flights, hypersonic vehicles

1. High-Speed Cruisers

Reducing travel times by going supersonic has only sense on long-distance flights. Range is hence an important figure of merit to evaluate high-speed aircraft concepts. It is strongly dependent on total available fuel mass and its consumption throughout the itinerary, i.e. from taxiing, speed-up cruise and final descent manoeuvres. Among these different parts, cruise represents a major portion of the needed fuel. The range achieved during cruise can be easily derived from the Bréguet range equation:

$$R = \frac{H}{g}\eta\frac{L}{D}\ln\left[\frac{1}{1-W_F/W}\right] = \frac{V_\infty}{g\,sfc}\frac{L}{D}\ln\left[\frac{1}{1-W_F/W}\right] \tag{1}$$

The range depends linearly on the energy content H in the fuel which can be increased with a factor of 2.7 by switching e.g. from kerosene to hydrogen. Despite its lower density requires larger volumes impacting negatively drag, it's still very worthwhile to do so seen the global performance increase. The aerodynamic performance given by L/D depends primarily on the Mach number and is decreasing asymptotically to a value of 4 to 6 with increasing flight Mach number. This decrease of aerodynamic performance would inherently exclude long-range supersonic flight as it would be economically not viable. However, the overall propulsion efficiency η increases with Mach number for turbojets and ramjets. The factors η and L/D have reverse dependencies on flight Mach number and for a first assessment the cruise efficiency ηL/D can be considered to be

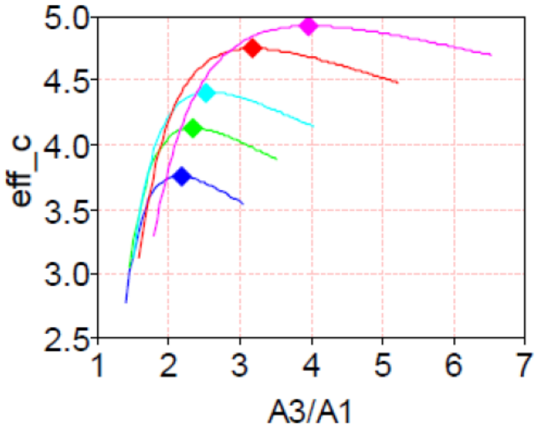


Figure 1. Cruise efficiency as a function of A3/A1 (nozzle/air capture area ratio) for Mach numbers between 3 to 6 [5].

constant, i.e. a value of about 3 to 4. An optimization analysis integrating both the aerodynamics and the propulsion unit on a two-dimensional conceptual design showed a potential cruise efficiency factor ηL/D beyond 4 for flight Mach numbers above 3.5 (Fig. 1). This means that the range is more or less independent of the flight speed and is then only determined by the relative fuel fraction WF/W or the structural efficiency.

These promising feasibility results as well as the remaining open questions with respect to variable engine cycles, materials, engine-airframe integration, thermal protection etc.… justify the need for more in-depth studies and analyses related to these disciplines. The LAPCAT project (Long-Term Advanced Propulsion Concepts and Technologies) has been set up to focus mainly on technologies related to engines and their integration into the airframe [1,7]. Material, structures and thermal protection technologies are addressed within ATLLAS (Aero-Thermodynamic Loads on Lightweight Advanced Structures) [8]. Both projects incorporate preliminary designs of supersonic and hypersonic cruisers with flight Mach numbers ranging from Mach 3 to 8. Detailed discussions and related references about the different vehicle concepts including the revisiting of American concepts can be found in [1,8]. Here, only the presently retained European vehicle concepts are highlighted. A conceptually optimized Mach 3 flight vehicle was configured in ATLLAS which allows countering the known lift drop at high speeds by expanding the engine exhaust over an as wide area as possible. The analysis indicated that venting the exhaust in the lee of the wing and base of the fuselage may enable a supersonic aircraft with cruise efficiency competitive with their subsonic rivals, whilst offering significant potential to reduce sonic boom. A vehicle configuration has been developed featuring a circular fuselage with nose intake and an internal high bypass turbofan (Fig. 2). Exhaust is ducted to the wing and fuselage bases. The wing has a high aspect ratio for good subsonic performance while drag due to thickness is eliminated by exhausting approximately two thirds of the propulsive stream from the wing trailing edge.

Another design approach maximized rather the thermodynamic engine efficiency by exploiting the liquid hydrogen fuel on board as lowest sink temperature (20K) in the

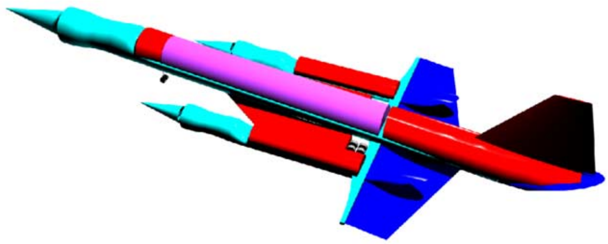


Figure 2. M3 Configuration with fuselage and wing skins off. Cyan: air flow path; blue: wing nozzle and thrust surfaces; red: fuel tanks; magenta: cabin.

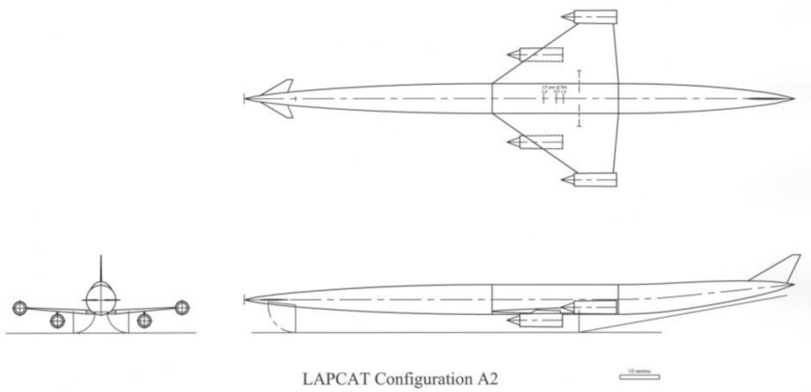


Figure 3. LAPCAT A2: Mach 5 hydrogen based vehicle (top) with precooled turbofan-ramjet Scimitar engine.

cycle. The hydrogen powered LAPCAT A2 vehicle flying at Mach 5 indicated that a 400 ton, 300 passenger vehicle could achieve antipodal range. The concept is particularly interesting for this mission requirements as a trajectory optimization allowed to fly almost continuously over sea and avoiding sonic boom impact when flying over land.

The proposed aircraft configuration A2 is shown in Fig. 3. The vehicle consists of a slender fuselage with a delta wing carrying 4 engine nacelles positioned at roughly mid length. The vehicle is controlled by active foreplanes in pitch, an all moving fin in yaw and ailerons in roll. This configuration is designed to have good supersonic and subsonic lift/drag ratio and acceptable low speed handling qualities for takeoff and landing.

The conceptual designs for a Mach 8 civil transport aircraft within LAPCAT II are all based upon dual mode ramjet to achieve these high cruise speeds. Still, as shown in Fig. 4, these preliminary design processes resulted so far in three quite different concepts: a TBCC design from ONERA/ULB/UNIROMA based on the PREPHA reusable launch vehicle [9,13], an axi-symmetric design from MBDA combining RB- & TBCC [10], and a TBCC based wave-rider concept from ESTEC [11,12]. So far, the waverider concept has been put forward for the ground-testing phase. A further review of the ground test results and nose-to-tail computations of the different configurations should finally result into the definition of a flight configuration.

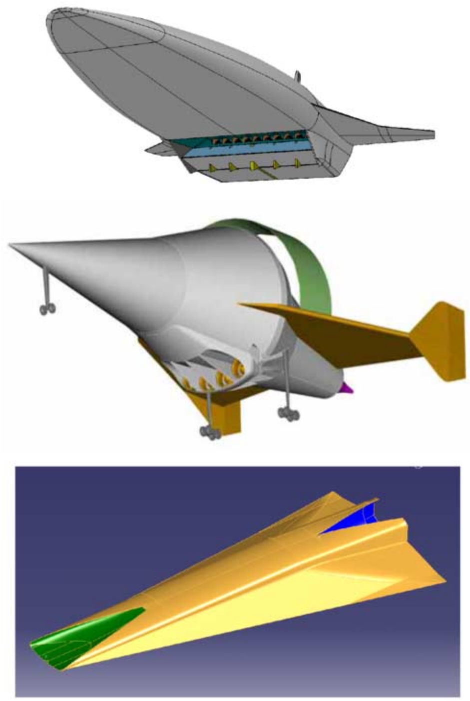


Figure 4. Layouts of 3 remaining Mach 8 vehicle concepts: PREPHA derived vehicle from Onera (top), axi-symmetric design from MBDA (middle) and waverider based design from ESA-ESTEC (bottom).

2. Suborbital Flights

The FAST20XX project, triggered by the FLACON outcome [3], aims at exploring the borderline between aviation and space by investigating suborbital vehicles. The main focus is the identification and mastering of critical technologies for such vehicles rather than the vehicle development itself. In principal, two main scenarios can be considered in suborbital flight depending on the required energy, i.e. low- and high-energy transportation.

The low-energy suborbital transportation concept is based on a space plane launched from an airplane offering essentially a ballistic flight experience using hybrid propulsion. This concept called ALPHA is comparable to the American SpaceShipOne vehicle. The possibility is foreseen to further develop this space plane envisioned to evolve into suborbital point-to-point long distance transport in very short term by using high energy propulsion (EVE-concept). An alternative, vertically launched two-stage rocket space vehicle system concept, SpaceLiner, is used to identify technologies required for suborbital long-range transport.

Though the low-energy ALPHA configuration [14–17] follows somehow the design of SpaceShipOne, it is rather driven by the successfully flown German RLV demonstrator Phoenix for which a large database is available. After a first design iteration loop, the size of the vehicle is 1.3 times the Phoenix vehicle, giving space to 2 passengers, one pilot and to host the propulsion and all subsystems (Fig 5). Based on the trajectory data, the g-loads during the individual mission phases are given in (Fig. 6a).

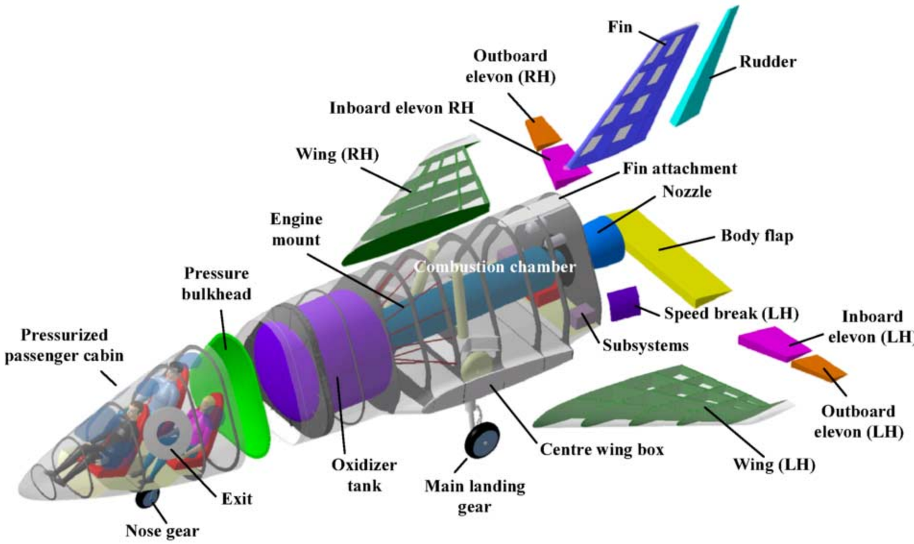


Figure 5. ALPHA vehicle structural concept.

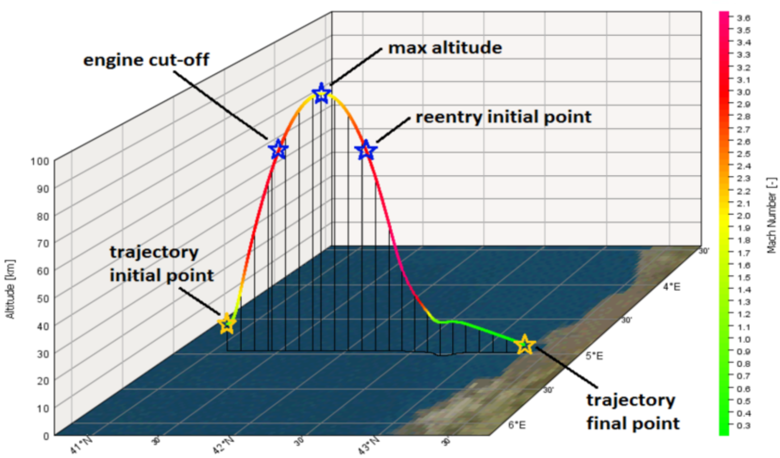


Figure 6a. ALPHA reference trajectory

During descent from 100 km to round about 30 km altitude high Mach numbers reflect the conversion of potential energy into kinetic energy. The reference trajectory at reentry implies moderate levels of acceleration up to a maximum of 3.2g (Fig. 6b).

The high-energy concept, SpaceLiner, was originally introduced by DLR [18] and is now maturing within the FAST20XX project [16,19]. It consists of a vertically launched two-stage rocket space vehicle system carrying 50 passengers over long distances at very short time (Fig. 7). Most promising routes are between Western Europe and Australia, but a lot of other interesting routes exist which might be served with some adaptations of the vehicle, e.g. a single stage concept for Europe-America routes. Hydrogen rich staged combustion cycle engines with a moderate chamber pressure are assumed for the propulsion system. In a first step, major subsystems like the active

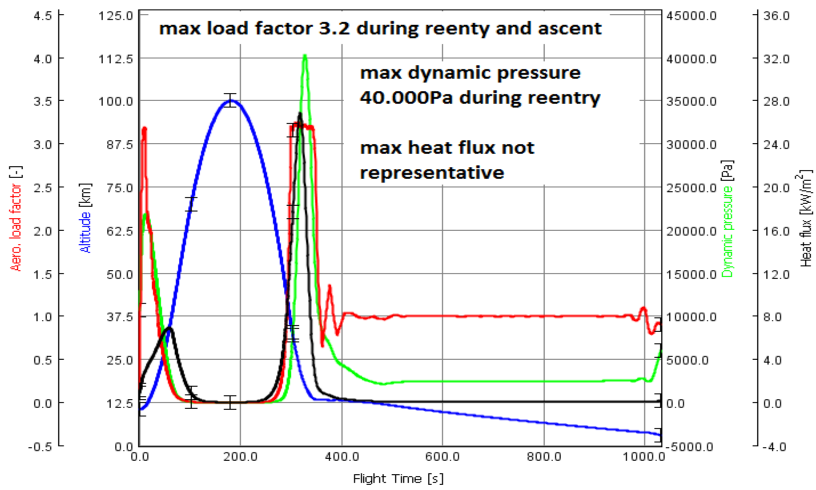


Figure 6b. ALPHA reference trajectory.

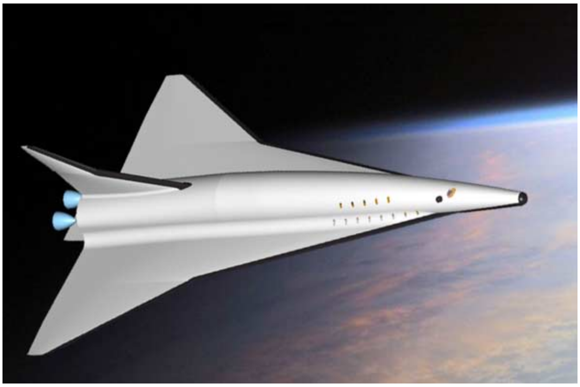


Figure 7. SpaceLiner "orbiter".

cooling system, passenger capsule rescue system, the avionics and control systems, the life-support and pressurised cabin system, and vehicle health-monitoring are conceptually designed. So far, the SpaceLiner baseline has a total propellant mass of 987 tons and a lift-off mass of 1,238 tons [16].

A typical SpaceLiner trajectory is shown in Fig. 8, where initially a skipping trajectory (black line) was selected to maximize the range of the "orbiter"; the acceleration during the skips varies between 0 and 1.1g. By adapting slightly the flight route a non-skipping trajectory (green line) can be realised (Fig. 8, right) at a small cost of a 0.3% higher fuel consumption. As it increases the passengers' comfort, the non-skipping trajectory is now considered as the SpaceLiner reference trajectory.

3. Critical Technologies

Apart from providing the characteristics and claimed performances of these vehicles, also the required technologies to achieve these goals are gradually developed including

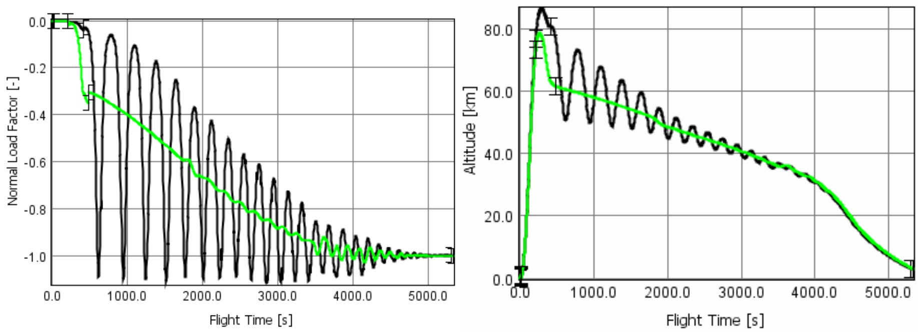


Figure 8. SpaceLiner trajectory (left) and load factors (right): initial skipping trajectory (black), optimised non-skipping trajectory (green).

the constraints imposed by the environmental impact. The technologies address specific needs of:

- Advanced combined engine cycles able to operate over a wide speed range;
- The characterization of high-temperature light-weight metallic, composite and ceramic materials;
- Active and passive cooling systems for internal and external thermally loaded components;
- Different storable and cryogenic fuel types;
- Multi-disciplinary and multi-physics optimization tools; and
- Finally the need of experimental campaigns at real flight conditions for validation with respect to high-speed aerodynamics and combustion, designed by existing European ground test facilities and state-of-the-art multi-dimensional and multi-physics numerical models.

The environmental issues entail not only the emissions of CO_2 or NO_X but also the effect of contrails, sonic boom and impacts on the stratosphere. Preliminary results indicate the feasibility of achieving fuel consumption and emission rates reaching nearly the same level as conventional aircrafts. Furthermore research is carried out on system safety design aspects. In addition non-technical aspects are addressed such as legal, regulatory and licensing topics as well as medical questions such as human limitations with respect to health risks and comfort.

References

[1] http://www.esa.int/techresources/lapcat_II.
[2] http://www.esa.int/techresources/atllas_II.
[3] J. Starke, J.-P. Belmont, J. Longo, Ph. Novelli and W. Kordulla, "Some considerations on Suborbital Flight in Europe", AIAA-2008-2525, 15th AIAA International Space Planes and Hypersonic Systems and Technologies Conference, Dayton, April 28 – May 1st, 2008.
[4] http://www.esa.int/fast20xx.
[5] T. Cain, M. Zanchetta and C. Walton, "Aerodynamic Design of the ATLLAS Mach 3 Transport", CEAS 2009 European Air and Space Conference, Manchester, UK, 2009.
[6] J. Steelant, "Sustained Hypersonic Flight in Europe: Technology Drivers for LAPCAT II", 16th Int. Space Planes and Hypersonic Systems and Technologies Conference, October 19–22, 2009, Bremen, Germany, AIAA-2009-7206.

[7] J. Steelant, “Sustained Hypersonic Flight in Europe: Mid-Term Technology Achievements for LAPCAT II”, 17th Int. Space Planes and Hypersonic Systems and Technologies Conference, April 11–14, 2011, San Francisco, USA, AIAA-2011-2243.
[8] J. Steelant, “Achievements obtained on Aero-Thermally Loaded Materials for High-Speed Atmospheric Vehicles within ATLLAS”, 16th Int. Space Planes and Hypersonic Systems and Technologies Conference, October 19–22, 2009, Bremen, Germany, AIAA-2009-7225.
[9] L. Serre and S. Defoort, “LAPCAT-II: towards a Mach 8 civil aircraft concept, using advanced Rocket/Dual-mode ramjet propulsion system”, 16th Int. Space Planes and Hypersonic Systems and Technologies Conference, October 19–22, 2009, Bremen, Germany, AIAA-2009-7328.
[10] F. Falempin, M. Bouchez and V. Perrillat, “LAPCAT 2 – Axisymmetric Concept for a Mach 8 Cruiser – Preliminary Design and Performance Assessment”, 16th Int. Space Planes and Hypersonic Systems and Technologies Conference, October 19–22, 2009, Bremen, Germany, AIAA-2009-7437.
[11] N. Murray and J. Steelant, “Methodologies involved in the Design of LAPCAT-MR1: a Hypersonic Cruise Passenger Vehicle”, 16th Int. Space Planes and Hypersonic Systems and Technologies Conference, October 19–22, 2009, Bremen, Germany, AIAA-2009-7399.
[12] N. Murray, J. Steelant and A. Mack, “Design Evolution for Highly Integrated Hypersonic Vehicles”, Space Propulsion 2010, San Sebastian, Spain, 3–6 May 2010.
[13] S. Defoort, M. Ferrier, J.L. Pastre, P. Duveau, L. Serre, D. Scherrer, C. Paridaens, P. Hendrick, A. Ingenito and C. Bruno, “LAPCAT II : conceptual design of a Mach 8 TBCC civil aircraft, enforced by full Navier-Stokes 3D nose-to-tail computation”, 17th AIAA Int. Space Planes and Hypersonic Systems and Technologies Conference, April 11–14, 2011, San Francisco, USA, AIAA-2011-2137.
[14] H. Adirim and N. Pilz, “Propulsion Options for Air-Launch Vehicles”, Deutscher Luft- und Raumfahrtkongress 2010, Hamburg, 31 August – 2 September 2010.
[15] H. Adirim, N. Pilz, M. Marini, P. Hendrick, M. Schmid, R. Behr, T. Barth, F. Tarfeld, A. Wiegand, D. Charbonnier, R. Haya Ramos, J. Steelant and A. Mack, “Overview of Suborbital Human Transportation Concept ALPHA”, 7th Aerothermodynamics Symposium, Brugge, Belgium, 9–12 May 2011.
[16] A. Mack and J. Steelant, “FAST20XX: First Progress on European Future High-Altitude High-Speed Transport”, AIAA, 17th AIAA International Space Planes and Hypersonic Systems and Technologies Conference, San Francisco, CA, 11–14 April 2011.
[17] A. Mack, J. Steelant and W. Kordulla, “FAST20XX: Future High-Altitude High-Speed Transport for the Next Decades”, Space Propulsion 2010, San Sebastian, Spain, 3–6 May 2010.
[18] M. Sippel, “Introducing the SpaceLiner Vision”, 7th International Symposium on Launcher Technologies, Barcelona, Spain, April 2–5, 2007.
[19] M. Sippel and A. van Foreest, “SpaceLiner Rocket-Powered High-Speed Passenger Transportation Concept Evolving in FAST20XX”, 61st Int. Astronautical Congress, Prague, September 27 – October 1, 2010.
[20] M. Sippel, A. van Foreest and C. Bauer, “System Investigations of the SpaceLiner Concept in FAST20XX”, 17th AIAA Int. Space Planes and Hypersonic Systems and Technologies Conference, San Francisco, 11–14 April 2011.
[21] A. Kopp, A. Van Foreest, M. Sippel, M. Dalenbrink and R. Jarlås, “Investigation of Structure for the Hypersonic Transport System SpaceLiner”, 17th AIAA Int. Space Planes and Hypersonic Systems and Technologies Conference, San Francisco, 11–14 April 2011.

About the Author

Johan Steelant
Section of Aerothermodynamics and Propulsion Analysis
ESA/ESTEC
Keplerlaan 1
NL- 2200 AG Noordwijk (The Netherlands)
Tel.: +31 71 565 5552
johan.steelant@esa.int
www.esa.int

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-394

Opening the Airspace for UAVs – ASTRAEA Progress Report

Nigel MILLS

Abstract. The ASTRAEA – Autonomous Systems Technology Related Airborne Evaluation and Assessment – Programme is a collaborative UK initiative drawing on the expertise of some of the world's aerospace companies to establish the necessary technology, procedures and regulations to enable the routine operation of unmanned air systems (UAS) in all classes of airspace. This presentation describes the systems approach and virtual certification process being adopted, the progress that has been achieved to date and sets out some key milestones in the future programme.

Keywords. UAV, UAS, airspace

1. The Challenge

Regulations for manned aviation have matured over the past 100 years as technology has been developed and lessons have been learnt. There is an implicit assumption in such regulations that the pilot of the aircraft is on board. In the case of an unmanned air vehicle (UAV) where the pilot is situated remotely this assumption is incorrect. Unfortunately there is no agreed interpretation of the regulations for unmanned air systems (UAS). However, the authorities have provided guidance that the operations of UAS should be transparent to other airspace users, the systems and rules should be equivalent and it should be no less safe that manned aviation. In the absence of formal specifications there is a "Catch 22" situation where regulators require an example system to certify but Industry cannot make the business case to develop one in the absence of a solid specification.

A second challenge is the perception of both professional aviators and the general public with whom we need to build trust that UAS are safe, have economic and societal benefit and improve European security.

2. The ASTRAEA Approach

The UK ASTRAEA programme was established in 2006 as a jointly funded Industry/Government initiative to bring regulators and Industry together (Fig. 1) so that UAS regulations could be matured and technology could be developed. The objective is to enable the routine use of UAS in all classes of airspace without the need for restrictive or specialised conditions of operation. This is being achieved by a whole system approach which will develop and demonstrate the key technologies and operating procedures required to open up the airspace.

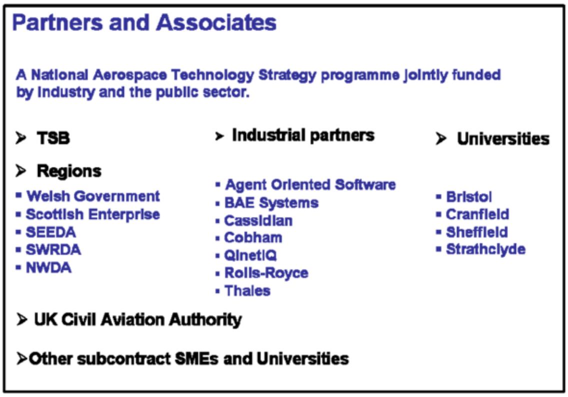


Figure 1. ASTRAEA Partners and Associates.

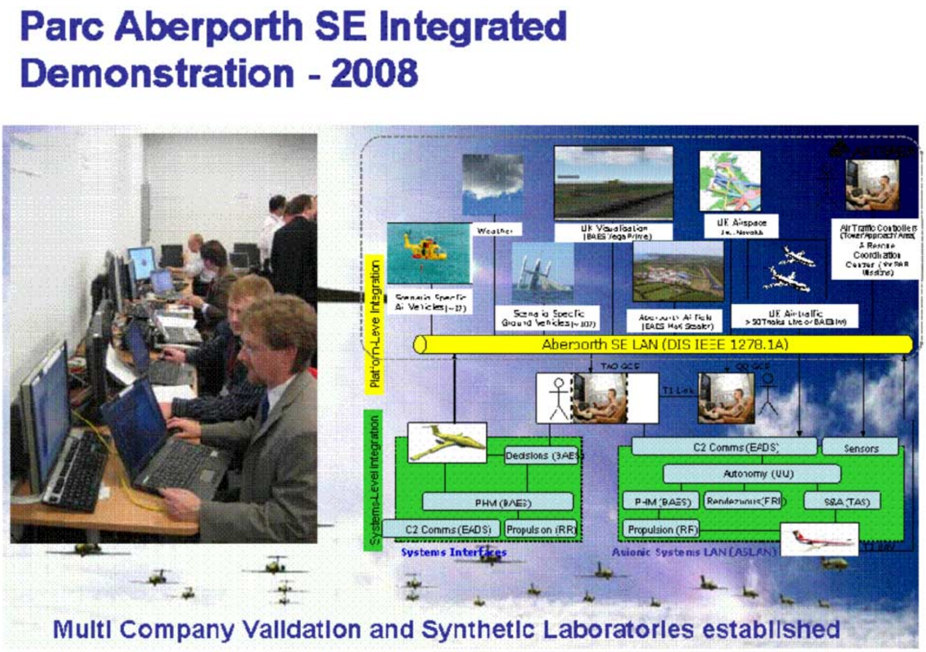


Figure 2. Parc Aberporth SE Integrated Demonstration – 2008.

Key activities are:

- Engagement of the regulatory authorities;
- Visualisation and experimentation in synthetic environments (SE) with validation of certain key technologies in flight tests;
- Collaboration with other international bodies.

The first phase of the programme ran from 2006 until 2008. It culminated with a synthetic environment demonstration at Parc Aberporth in Wales of an end-to-end UAS mission in which two UAVs were operated in a search and rescue scenario (Fig. 2). It

was performed in front of a wide range of stakeholders including regulators, potential users, service providers and funding bodies.

The focus on performing an end-to-end demonstration had the benefit of eliciting concepts of operation, exercising the individual technologies and ensuring the integration had no undesirable emergent properties. It also established multi-company validation and synthetic laboratories.

3. Transition from SE to Flight

Phase 2 of the programme has been running since 2009 and comprises two main projects as described below. Both projects are undertaking a series of trials and demonstrations and are contributing to the development of regulations by engagement with the UK Civil Aviation Authority (CAA) in a Virtual Certification exercise described further.

3.1. Separation Assurance and Control

This project covers technology development in the areas of sense and avoid (to replace the pilot's see and avoid responsibilities), ground operations and human systems interaction (a key aspect to ensure the remote pilot has adequate situation awareness) and communications systems and spectrum (to ensure that the command, control and payload links are secure, have high integrity and have access to adequate RF spectrum).

The SE trials from phase 1 of the ASTRAEA programme have transitioned into flight. A manned Flying Test Bed (FTB) is being utilised as a surrogate UAV. Key technologies are used in flight to direct the FTB aircraft via the on-board flight navigation system whilst the flight deck crew (pilots) remain in charge at all times and provide the "See and Avoid" (human eye) capability required by current regulations. Use of the FTB in this manner allows the technologies to be safely flight tested and demonstrated outside segregated airspace without recourse to special airspace clearances.

Evidence from the 12 month period of flight trials which commenced in February 2011 is that the system performs at least as well as the flight crew.

3.2. Autonomy and Decision Making

This project covers autonomy, decision making and contingency management (to support the remote pilot in the event of comms failure, time critical decisions or emergency situations) and operational utility and affordability (to understand the business case for civil use of such systems).

The architecture and operational concepts from the first phase of the programme have been matured to the point that the systems requirement is documented. Integrated AI modules (agents) and reasoning toolsets have been developed to implement the machine intelligence necessary to optimise task/sensor suite performance and maximise efficiency of operation.

Two key modes of decision making are proposed:

- Human in the loop (data link present and non-time critical decisions) having full system functionality. The UAV pilot is in the command and control loop and authorises every decision;

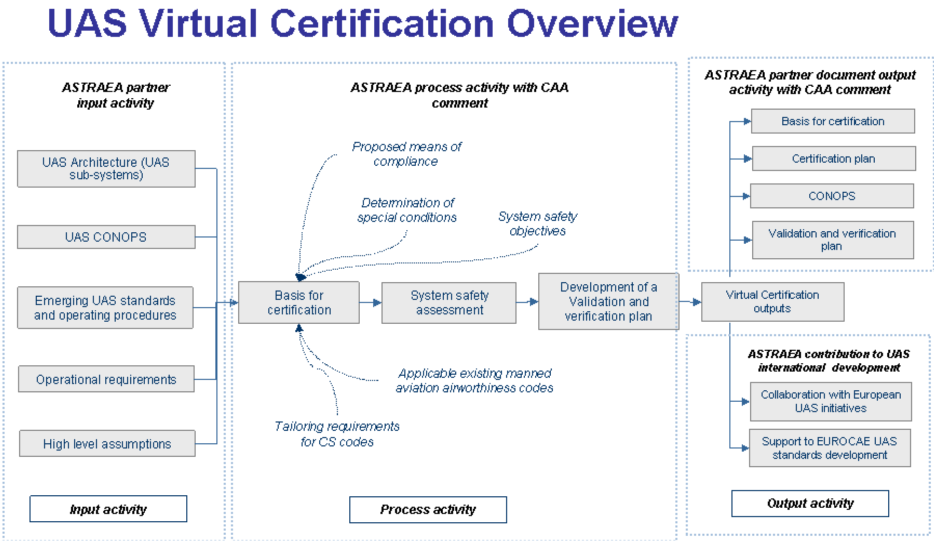


Figure 3. Virtual certification process.

- 2. Machine based decisions (data link not present or time critical decisions) with reduced decision making set focussing on safety functions;
- Integration trials of autonomous mission management and a ground control station have taken place in 2011 and this is expected to transition to a flight trials in 2012.

4. Virtual Certification

A recent innovation within ASTRAEA has been the concept of Virtual Certification. This is a process in which the consortium is creating and agreeing a generic system architecture for a UAS which is then used as the basis for structured discussion with the CAA to provide guidance on an acceptable technical and regulatory framework leading to certifiable solutions. This process will expose the salient issues to allow any novel or UAS specific aspects to be considered beyond conventional CS23 or CS25 codes. The outcome will be a route to certification plan, a strategy of how to achieve this, and suggested adaptations of regulations (Fig. 3).

5. User Group

An important aspect for the government and industry funders of the ASTRAEA programme is the establishment of a successful UAS market. Therefore, the programme has established a user group to which interested parties are invited to contribute their requirements. A questionnaire has been developed which is being used to stimulate discussions with the users so that the business constraints can be taken into account when devising system solutions to the UAS operations and equipment. Users are being sought across a wide range of applications including many different types of data gathering, airfield services and support to manned operations.

6. Conclusions

ASTRAEA is a unique programme which will enable a new branch to the aerospace industry and enable new services to meet the requirements of a wide range of end users.

ASTRAEA will create opportunities for manufacturing and service industries in the emerging UAS market and related intelligent technology applications and will give industry the knowledge and confidence to develop certifiable products and services to address these markets.

The technologies developed in ASTRAEA are potentially capable of broad application in other sectors and provide the confidence for further investment in UAS product development.

About the Author

Nigel Mills, Technical Director Air Technology Insertion, QinetiQ
Cody Technology Park, Ively Road, Farnborough, Hants, UK, GU 14 0LX
Tel.:+44 1252 394 594
njmills@qinetic.com
www.qinetic.com

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-399

The Greening of Aerostructures – Challenges Ahead

Miguel Á. CASTILLO ACERO

Abstract. Aernnova, as a consolidated aerostructures Tier 1 company, is constantly improving more eco- friendly design and manufacturing solutions for the Aerostructures Life Cycle. This is not only about the reduction of harmful chemical treatments or the efforts to provide better aircraft architecture features to reduce noise, emissions and increase efficiency, but also, the different research and development efforts to use materials in general, and composites in particular, to save weight and improve aerodynamics at their full capacity.

Keywords. Contamination, chemical treatments, greening aero-structures, smart materials

1. Characterisation of the Contamination Related Drivers

Let us start with the Product Development- Design activities. To reduce the impact of design activities on the environment is quite obvious that a simplistic approach concludes that it is required an improvement on the efficiency by reducing the development cycle time. The Parameter to monitor is the reduction of energy consumed by the design engineers and their machines, mainly computers, to define the product.

On the other hand, a good design enables among others, the following benefits along the Product Life Cycle of the aerostructure:

- The reduction of energy consumption during production;
- The elimination of harmful toxic contaminants;
- A better materials disposal, waste disposal, ability;
- The reduction of maintenance cycle time;
- The reduction of drag to reduce fuel consumption and therefore the carbon footprint;
- The reduction of weight, also for fossil fuel consumption minimization;
- The complete elimination of CO2 emissions by non carbon fossil fuelled airframe design concepts, i.e. hydrogen solutions.

The balance, from environmental perspective, is in the side of performing a better design against the principle of reducing developments cycle time. The benefits along the aero-structures life cycle overtake the penalties on the energy wasted during the development phase by far.

This new design environmentally oriented paradigm must be harmonized with the intrinsic “safety first” aerospace principle together with business and competitiveness oriented way of working.

From pure Manufacturing point of view, aviation industry is working on raw materials optimization and handling, the reduction on the water consumed along the different production processes and proper ways for composites disposal.

Also, in conjunction with product development, there are efforts on reducing the energy consumption on production and the elimination of harmful toxic contaminants.

Regarding the Maintenance and End of Life Cycle Contamination, the situation today is clearly targeted for improvement. Only a little more than 50% of the airframe metallic materials are re-cycled and the rest is stored in desert areas with little control on soil contamination. There is a need to cascade down ISO 14001 requirements for the end of commercial airplanes life cycle.

The two main commercial aircraft manufacturers, Boeing and Airbus, are working to define the most efficient way for the end of aircrafts life cycle. Airbus is working in the program Pamela- Life and Boeing in the initiative AFRA. Both OEMs are demonstrating their implication on the development of industrial profitable solutions together with their supply chains.

The main aircraft emissions during Operation are listed below together with their key characteristics:

- CO_2 is directly linked to fuel consumption also proportional to weight and drag. It is greenhouse gas. Its effect is global extension and long term duration;
- NOX. It is caused by the engines. Its effects are located at high altitude (ozone destruction) and in the airports vicinity, low air quality. It is a mid- term duration impact type;
- Sulphur and other solid particles. They affect the air quality and they are short term duration type of contamination.

2. Air Transport Boundary Conditions: Growth and Actions

According to all validated sources and based on data logs, air transport growth between 4 and 5% per year. In the other hand, Statistics show a historical trend of a minimum 1.5% efficiency improvement per year.

The direct conclusion is that in order to maintain current impacts on environment we need to increase minimum 2.5 % the efficiency to make air transport sustainable. Therefore, the Sector needs actions at all levels [2,7].

In the engine specific consumption reduction, research and innovation framed inside some key elements aspects:

- New engines concepts:
  - Open rotor;
  - High by pass ratio;
  - Geared fan.
- Development of new materials for high temperature applications.

In the field of airframe design and to include the most relevant areas for technology development, we can highlight the Drag and Weight reduction efforts.

There are also actions identified in the field of operational procedures, with new ATM (Air Traffic Management) technologies enabling Flex-Airways, Approaches and Take off paths with less environmental impacts. Efforts on airports improvements.

Finally, we have to remember the contamination mitigation through using alternative fuels, bio-fuel and the development of technologies to enable the safe use of alternative fuels like hydrogen.

3. Greening Aero-Structures – Design

The Greening Efforts must start with an aeronautics classic and traditional issue which is the weight.

Current big trend is to use composite materials but we have to remember first the research of Lighter Metallic Materials with enhanced characteristics. The selection of the right metallic material is in the base of a light design success. For example, the selection of aluminum alloy depends on enhanced mechanical properties required for the structural application, critical failure mode, sizing loads environment, etc.…

Today there are new aluminum alloys, i.e. aluminum-lithium with less density than current aluminum alloys and mechanical properties improved. These mechanical enhanced properties together with weld ability enablers might be a winner in future aircraft structures. Research and innovation on aluminum and titanium alloys are in progress and may show results in the coming years. Just to name some of the current Research Lines, we can identify the laser beam welding technologies, friction steer welding; improve industrialization efforts, integration of inspection and welding operations, and automation and robotization.

The star materials in aerostructures domain are the composites and in particular Carbon Fibre Reinforced Composites. There has been a continuous growth of their utilization achieving by large the 50% of the overall structure of the latest models: Boeing 787 and Airbus A3 50 XWB. The demand now is to enhanced composites essential properties.

There are several Research and Innovation paths to improve Composites Utilization in Aero- structures. One of the main efforts in Aernnova is through the use of Structural Health Monitoring Systems. This type of Systems allows detecting impacts and defects on the aircraft structure in real time. The Potential Benefits on Installing a SHM on an aircraft Structures are huge:

- Reduce direct maintenance costs of structures;
- Eliminate all common non-destructive inspections;
- Simplify and optimize future maintenance procedures and strategies;
- Make possible real Condition Based Maintenance of structures;
- Increase structure availability at minimum cost;
- Increase and improve transport safety;
- Increase quality assurance of final products;
- Integrity monitoring of damage tolerant structures;
- Optimize for shape & mass future structures based on Fully Stressed Design;
- Identification of critical areas of structures during their service;
- Structures with autonomous and automated maintenance;
- Reduction of Time to Market (TTM);
- Make easier identification of real causes of possible structural damages;
- Have the information of structure consumed & remaining life at all moment.

Aernnova is currently developing its own SHM system, called PAMELA SHM TM.

Just to include other composite- enhancements aero-structures Research and Innovation efforts we can highlight:

- Multifunctional materials;
- Niño technology for mechanical enhancements: nanotubes and similar;
- Electrical enhancements;
- Parts integration into one shot features;
- Thermoplastics;
- Technologies out of autoclave.

Regarding new Research and Technology trends we can remark efforts on Innovative Conceptual Design at a/c level, to Develop New Architectures, New Engine integration, Tailless design and other revolutionary concepts. In particular we can highlight Loads alleviation technologies, with Smart Materials and Morphing Structures.

4. Greening Aero-Structures – Manufacturing

There are different areas on Manufacturing side where to put attention on the definition of a greener manufacturing way than current situation. Just to name the main areas to focus on we can identify five big Research and Innovation lines:

- Manufacturing specialization on product types: composites, metallic, assembly to optimize operations;
- Simulation precedes actions at industrial lay outs;
- Energy management;
- Waste management;
- Concurrent design to minimize scrapped materials.

In particular, in Aernnova, the Materials and Process down selection is performed in full concurrency with the Design office and then provides better results. The consideration of environmental requirements starts at the beginning. Also this way of working produces a closer look on the raw materials availability, their costs and what are going to be the environmental effects and the energy consumption during the cycle.

5. Aernnova Is Associated to CLEAN SKY/ SFWA

Aernnova is a proud Clean Sky associate. Aernnova is collaborating in the Smart Fixed Wing Aircraft Integrated Technology Demonstrator called BLADE: Breakthrough Laminar Aircraft Demonstrator in Europe. The accelerated research process up to Technology Readiness Level (TRL) 6 that Clean Sky offers to a company like Aernnova represents an unprecedented opportunity for rapid progress in the introduction of green technology into aviation. Clean Sky SFWA will demonstrate and validate the technology breakthroughs that are necessary to make major steps towards the environmental goals. The SFWA ITD, with the BLADE demonstrator, will work towards the goal of reducing the medium- and long-range aircraft fuel burn and emissions by around 10%

to 20% and noise by 5 to 10dB. Furthermore, it will enhance the comfort and safety of future transport including aircraft agility and flight trajectory flexibility. With the foreseen increase in air traffic in mind these goals will not be reached without a step change in aircraft technology, which is precisely the challenge for the BLADE project.

The objective of the SFWA ITD is not to start up new research, but to take existing research much further on the TRL level. Technologies that have been developed through research, partly funded by the European Commission, over the last 20 years, will be matured and enhanced to a TRL that can be implemented on the next generation of civil aircraft.

The SFWA, the Clean Sky ITD where Aernnova is one of the associates, aims to develop and test an all new “smart wing” design that makes use of passive and active flow and load control technologies and will help to reduce the drag of the wing in cruise. This concept will increase overall aircraft fuel efficiency. The architecture of the smart wing will enable the application of the most advanced passive and active loads control strategies, which are reducing the loads in turbulence not only acting on the wing, but also on the entire aircraft. One key exercise in the SFWA will be not to develop the “smart wing” so much as an individual component, but rather to pursue its full optimization and integration into the overall aircraft concept. This will include all disciplines traditionally involved in aircraft design: flight physics, structure and systems.

Aernnova together with Airbus [5], Saab [6] and the rest of this Smart Wing Clean Sky BLADE project partners, will demonstrate the concept feasibility by a Flight Test Bed (FTB) Demonstrator in an A340. The selected technology is the Natural Laminar Flow (NLF) because is most cutting energy. To achieve this NLF wing more than usual challenging requirements must be fulfilled. Aernnova is either collaborating with the rest of associates and partners or directly working in the following topics:

- Rivet less upper surface and Very Tight surface waviness, roughness, see references [1,3,4,8–10];
- Very high Quality Assembly Tooling Computer-Aided Assembly CAA (with Integrated Metrology);
- Manage, Predict and Control all the parameters that affect the Assembly from the smallest detail to the biggest in order to industrialize the NLF Wings (Numerical Simulation), see references [11–19];
- Metrology capabilities, the current technology is not capable of measure the tight waviness with guarantee;
- Development of advanced mechanical bonding;
- Development of post-assembly finishing and coating alternatives.

The fulfilment of all these requirements is not easy they are at levels not seen before in commercial aviation. The new wing has to be smoother than current state of the art solutions. The development of new ways to design and build the wing oriented to achieve this extra requirements performance will enable larger natural laminar flow region on the aerodynamic wing profile.

Regarding overall wing configuration after the inclusion and fulfillment of all these requirements, the result will not look like nowadays´ commercial aircraft wings:

- The leading edge will be reduced, height and curvature;
- The wing overall sweep angle will also be reduced.

Just to name the main areas on current Technology Development in Aernnova to cope with the BLADE SFWA Clean Sky project we can highlight the efforts on simulation, 3D modeling, robust and integral structural analysis, virtual testing and design reliability. In the field of aerodynamic performance, there are Technology Development efforts on using Composites for complex aerodynamics shapes with anti- erosion enhancements like thinning metal foil and challenge these with nano-technology enhancements.

6. Conclusions

The combination of the Air Transport growth and the Emissions historical improvement trend concludes a yearly deficit between 2 and 3 %. This situation frames a real need to advance on the technologies utilize along Aviation Sector.

In particular, for Aero-structures, these greening requirements combined with safety and economics defined the new paradigm to succeed. The OEMs, Tier 1 like Aernnova and all "Extended Enterprise" Players, are developing technologies to cope with this new paradigm. The Natural Laminar Flow Wing and the Structural Health Monitoring systems are good candidates to be successful on these new grounds. Integrated Projects like BLADE SFWA Clean Sky provide a way to mature these rising technologies to an adequate level before commercial utilization.

References

[1] "Wing Leading Edge Joint Laminar Flow Tests", Aaron Drake, Russell V. Wetphal, Fanny A. Zuniga, Robert A. Kennelly Jr. and Dennis J. Koga, NASA, 1996.
[2] "Environmentally Responsible Aviation (ERA) Program", Tony Strazisar, NASA, 2009.
[3] "The Next Decade in Commercial Aircraft Aerodynamics (A Boeing Perspective)", Mark Goldhammer, KATnet II Conference on Key Aerodynamic Technologies, Bremen, Germany, 2009.
[4] "Challenges for Aerodynamics Engineers for Future Aircraft Design (An Airbus Perspective)", Behrooz Barzegar, KATnet II Conference on Key Aerodynamic Technologies, Bremen, Germany, 2009.
[5] "New Technologies from Airbus", John Blanchfield, OMEGA Conference, London, 2008.
[6] "Green Aircraft Technologies (Saab Perspective), Göran Bengtsson, Green Aircraft Conference Torino, 2009.
[7] "Innovation in Flight", Joseph R. Chambers, NASA, 2005.
[8] "Roughness and Waviness Requirements for Laminar Flow Surfaces", Clifford J. Obara and Bruce J. Holmes, NASA, 1985.
[9] "Design Considerations of Natural Laminar Flow Airfoils for Medium-Speed Regional Aircraft", Jan Roskam, Kansas University-NASA Grant, 1984.
[10] "Optimized Natural-Laminar-Flow Airfoil", J. Driver and D.W. Zingg, University of Toronto, 2006.
[11] "Variation simulation of fixture assembly processes for compliant structures using piecewise-linear analysis", Michael Leon Stewart, Master Thesis, Brigham Young University, 2004.
[12] "Tolerance Analysis of 2-D and 3-D Mechanical Assemblies with Small Kinematic Adjustments", K. Chase and S. Magleby, Department of Mechanical Engineering Brigham Young University, 1996.
[13] "Tolerance Stack Analysis Methods. A Critical Review", F. Scholz, Research and Technology Boeing Information & Support Services, 1995.
[14] "Mechanical Tolerance Stack-Up and Analysis", Bryan R. Fisher, Ed. Marcel Dekker.
[15] "Review of statistical approaches to tolerances analysis", S.D. Nigam and J.U. Turner, Computer-Aided Design, Vol. 27, No. 1, 1995.
[16] "A review of tolerance analysis of mechanical assemblies", C. Mavroidis, Department of Mechanical and Aerospace Engineering, Rutgers University, 2002.
[17] "An Introduction to Tolerance Analysis of Flexible Assemblies", K.G. Merkley, K.W. Chase and E. Perry, Brigham Young University Report.

[18] "An integrated methodology for statistical tolerance analysis of flexible assemblies", Alan J. Mortensen, Master Thesis, Brigham Young University, 2002.
[19] "Finite element modeling and optimization of load transfer in multi-fastener joints using structural elements", J. Ekh and J. Schön, Composite Structures, 2008.

About the Author

Miguel A. Castillo Acero
Vice President Technology Development AERNNOVA
Avenida de Manoteras, 20, 5th Floor
28050 Madrid (Spain)
Tel.: +34 913827844
miguelangel.castillo@aernnova.com
www.aernnova.com

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-406

ENFICA-FC: Design and Flight Tests of a Fuel Cell Powered Aircraft

Giulio ROMEO, Fabio BORELLO and Gabriel CORREA

Abstract. Growing interest in the application to renewable energy sources has led to a rapid development of fuel cell technologies. From the successful attempts of these technologies in the automotive industry, fuel cells could become the main power source for small general aviation aircraft or could replace APU and internal sub-systems on larger aircraft, to obtain all-electric or more-electric air vehicles. There are several potential advantages of using such a power source that range from environmental and economic issues to performance and operability aspects. The main objective of the European Commission funded project ENFICA-FC (ENvironmentally Friendly Inter City Aircraft powered by Fuel Cells) [1–11] was to develop and validate the use of a FC based power system for the propulsion of more/all electric aircraft.

Keywords. Fuel cell, hydrogen tank, inter-city aircraft, battery pack

1. Two Key Objectives

The ENFICA-FC consortium (coordinated by Prof. G. Romeo) consisted of 9 partners. Within the course of the ENFICA-FC project, which was launched in October 2006, two key objectives were attained:

- A feasibility study was carried out to provide a preliminary design of Inter-City aircraft power systems that could be supplied by fuel cell technologies; the safety, certification and maintenance concepts were also defined. Parametric sizing of different aircraft categories (from two-seater aircraft to 32 passenger commuters) was performed [4,5]. The study led to a better understanding of the practical meaning of transition from kerosene to hydrogen in transport airplanes.
- A two-seater electric-motor-driven airplane, powered by FC, was assembled and tested. The FC system, the hydrogen storage system and the electric and electronic system were installed in a light sport aircraft RAPID 200 which was flight and performance tested as proof of the functionality and future applicability of this system for inter city aircraft.

2. Design of Conversion Aircraft

After the selection of the proper aircraft for conversion [6], a complete, but limited, mission profile definition was first selected to show the feasibility of a new concept propulsion system. The requirements were chosen [3,6] to guarantee that the mission could be flown while keeping the total weight at around 5500 N, i.e maximum total weight at which original RAPID200 was tested.

An extensive CFD analysis was performed to define power requested for flight, concerning not only the overall aircraft, but also critical component as the engine cowl [7,11] that must guarantee a proper cooling of the different systems installed in the engine bay and provide a passive safety system for prevention of hydrogen accumulation. Predicted requested powers were found to be about 38 kW for climbing phase and 18–20 kW for cruising phase.

A particular architecture was adopted for the power system in order to achieve a safe and flyable aircraft for the prescribed mission: a battery system was added as a secondary power source to increase the rate of climbing during the most power-demanding phases (take-off and climbing to 500 m altitude). While fuel cells is always providing up to its maximum power output (20 kW) for normal flight (cruise and descending); the battery was designed to supply 20 kW for 18 minutes. During roll-out tests a fuel cell only take-off was also simulated to demonstrate, from a performance point of view, the capability of a fuel cell only complete mission.

Having two completely separate power source has a strong impact on flight safety, which is the main driver for all decision taken during design; the battery is designed so that it can work as an emergency power source in case of failure of fuel cell, allowing pilot to safely land.

Introduction of the second power source requires a more complex electronic control system; it's necessary indeed that fuel cell is always automatically selected as the main power supplier in order to minimize battery use that is "activated" only when requested power exceed fuel cell maximum one; at the same time the controller needs to be able to instantly draw power from battery to replace fuel cell in case of fuel cell malfunction.

The conventional power system (ICE), is very different from the fuel cell powered airplane both for number of items and for volumes of those items and aircraft balance must be maintained, keeping in mind safety constraints that are particularly important when operating with high pressure hydrogen [6]. Main properties of the Rapid 200-FC aircraft are:

Maximum take off weight: 5500 N; Maximum level speed: 190 km/h; Cruise Speed: 150–160 km/h.

Maximum engine power: 42 kW; Endurance: 1 hr; Wing span: 9.9 m; Wing area: 11.85 m^2; Overall length: 7.0 m. Weight of subsystems are:

Empty Aircraft: 2210 N; Fuel Cell System: 1030 N; Pressurized Hydrogen Sub System: 510 N; Electric Motor: 400 N; DC/DC+AC/DC+ vehicle power control Sub-System: 140 N; Battery Packs: 510 N; Pilot: 740 N (limit of one passenger instead of two).

Some structural components were carefully re-designed: engine mount as support for many different subsystems (Fig. 1), special lightweight support plate for hydrogen tanks (Fig. 2), etc.

A new propeller was also designed, manufactured and tested since weight and available power of the converted aircraft strongly differ from the conventional one.

3. System Testing

Several experimental test activities have been performed at different levels of growing integration.

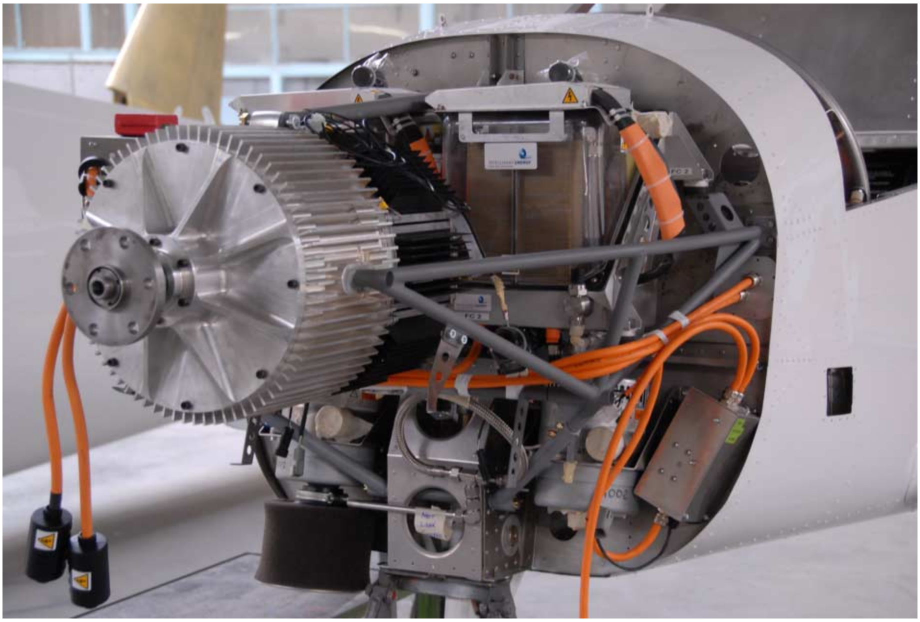


Figure 1. Engine bay installments of the fuel cell.

Figure 2. Installment of the high pressure hydrogen tank.

3.1. Individual Sub-System Testing

The fuel cell was carefully tested against endurance at its maximum power output. The system was continuously tested for more than 6 hours with no degradation of performances during the experiment. Several long tests were performed to prove reliability of the FC system [8].

Tests of battery system regarded mainly the safety of the system during charge and discharge; particular attention was paid to temperatures and minimum voltage during discharge; in fact, for safety reasons, the battery system isn't provided with automatic cut-off, so that the pilot is able to draw all the energy accumulated, eventually damaging battery, in order to safely land during an emergency.

Motor, power electronics and vehicle controller were simultaneously tested, mainly the temperatures that can be reached during a full duty cycle; above all at the very beginning of the mission, when airplane speed, an so fresh air mass flow, is very low. Temperature behaviors of critical components during the tests showed that the maximum temperature reached in the inverter was of 78° C (maximum allowable is 120°C), and in the motor was of 80°C (maximum allowable is 180°C). Moreover the vehicle controller was tested against its capability of being able to immediately switch from the main to the second power source, and back, without any interruption or unexpected change of motor operation.

Hydrogen storage system (350 bar is the working pressure for this application) was tested against maximum working pressure (438 bar) and burst pressure (984 bar).

3.2. Semi-Integrated System Testing

The whole fuel cell system was completely installed in the final configuration on a fuselage mock-up; the motor/power electronic block was linked to a bench brake; hydrogen was supplied at first by external hydrogen bottles until the system was proven reliable and then by the actual hydrogen system. Main goal of this testing stage was to investigate and tune the communication between systems, above all vehicle controller and fuel cell. Moreover fuel cell system is extremely complex and opportune strategies needed to be defined to pilot it during normal and abnormal operations that may occur during flight; extensive testing was hence devoted to software related issues and tuning.

3.3. Integrated System Testing

The final and most extensive campaign test was the one devoted to the complete aircraft (Fig. 3); ground test and flight test were performed at Reggio Emilia airport with the goal to validate the design and installation of the complete converted aircraft.

This stage mainly investigated the behavior of output power when connected to the real load (i.e. the propeller), behavior of propeller, handling of system partial failures, temperatures with the real cooling system (i.e. cooling system exposed to aircraft speed) and finally aircraft performances in take-off and cruise. Great attention was paid to correct handling of the two onboard power sources, testing several scenarios in which different failures were simulated.

Having the complete system installed on board allowed checking the real efficiency of cooling systems. In order to investigate this, temperatures were observed during high speed roll-outs which were performed for testing theoretical data about taking-off

Figure 3. Rapid 200FC during flight test (Copyright G. Romeo).

distances and speeds; cooling systems presented a very satisfactory behavior keeping temperatures below admissible limits.

After this extensive test campaign, the aircraft finally flew at Reggio Emilia airport. Six flights were performed, starting from a first 2 minutes maiden flight and ending with speed world record attempt for electric aircraft powered by fuel cells according to the draft FAI sporting code Class C, Aeroplane.

Flight path was chosen so that the aircraft was always able to land at the airport or at a close airfield, gliding with no available power. The main results obtained during flights [9,10] were:

- A maximum endurance of about 39 minutes, being the limiting factor the water consumption used for the stack humidification; the water tank capacity was undersized and needs to be reconsidered in future development; hydrogen measured pressure was 100 bar at the end of that particular flight in which a drop of 5.9 bar was recorded for each minute of flight;
- A maximum average speed (according to FAI definition) of 135 km/h was recorded during the best world record attempt; the speed was measured during two continuous 3 km long runs and with an altitude variation of less than 100 m between the start and the finish points;
- A maximum speed of 158 km/h was reached during level flight; with a top speed of 180 km/h, which was measured during several diving and pull-up manoeuvre tests. The total GPS Horizontal Path Length for a flight (Taxi + roll out + climb + horizontal flight + landing) was 76,5 km.

4. Conclusions

The extensive experimental campaign carried out, as well as the theoretical estimations, have proved that fuel cell technologies represent a promising innovation in aeronautics as a key-enabling technology for all-electric, zero emission, low noise aircraft.

The experience positive handling qualities and satisfactory engine performances led the team to consider these successful flights as a good starting point for further long endurance high speed flights. At the moment, for general aviation aircraft, fuel cells and the related technologies seem to need improvement from the gravimetric efficiency point of view; the actual one does not allow the same performances to be achieved as the original aircraft; a mid-range technology development would be sufficient to obtain acceptable performances.

The real strength of the "all-electric aircraft" concept does not lie in an improvement in the performances, but in the environmentally friendly use of the aircraft itself; such an aircraft could be used in airports surrounded by urban centers, during the night and in an environments that are restricted because of excessive pollution risk.

The results obtained during the projects can be considered as a further step in the European and World Aeronautics Science field towards introducing zero emission flight.

Acknowledgments

The authors acknowledge the important contribution made by the European Commission funding the ENFICA-FC, EC 6th FP programme – Contract No. AST5-CT-2006-030779 (2006–2010). The authors also acknowledge the contribution of the Consortium partners.

References

[1] Glover B. "Fuel Cells Opportunity", *Proceedings of AIAA/AAAF Aircraft Noise and Emissions Reduction Symposium*, Monterey, USA, May 2005.
[2] Volker H. "Airbus Fuel Cell Systems for Aeronautic Applications. A Clean Way from Kerosene to Energy", *Proceedings of 25th ICAS Congress*, Hamburg, D, Sept. 2006.
[3] http://www.boeing.com/news/releases/2008/q2/080403a_nr.html – April 2008.
[4] http://www.dlr.de/en/desktopdefault.aspx/tabid-1/86_read-18278/ – July 2009.
[5] http://www.enfica-fc.polito.it/.
[6] Romeo G., Moraglio I. and Novarese C. "ENFICA-FC: Preliminary Survey & Design of 2-Seat Aircraft Powered by Fuel Cells Electric Propulsion", *7th AIAA Aviation Technology, Integration & Operations Conference (ATIO)* – September 2007, Belfast, Northern Ireland, AIAA-2007-7754, pp. 15.
[7] Romeo G., Borello F. and Correa G. "ENFICA-FC: Design, Realization and Flight Test of All Electric 2-Seat Aircraft Powered by Fuel Cells". *27th Int. Conf. of the Aeronautical Sciences (ICAS 2010)*, Nice (F), 19–24 Sept. 2010. ISBN: 978-0-9565333-0-2.
[8] Shavit Z. "Fuel Cell Propulsion for All-Electric and More-Electric Aircraft and the ENFICA-FC Project", *Proceedings Annual Conference on Advanced Energy Sources (IFBC 2008)*, Tel-Aviv, Israel, January 2008.
[9] Pistecky P., Mikulka Z., Shavit Z., Miller N., Verstraete D. and Romeo G. "Analysis, Installation and Mission Performance of the Fuel Cell All-Electric Intercity Transport Aircraft". Technical Report D4.4 ENFICA-FC. 2009.
[10] Romeo G. and Borello F., "Design and Realization of a 2-Seater Aircraft Powered by Fuel Cell Electric Propulsion", *The Aeronautical Journal*, Vol. 114, n. 1155, May 2010.
[11] Romeo G., Cestino E., Borello F. and Correa G. "Engineering Method for Air-Cooling Design of Two-Seat Propeller Driven Aircraft Powered by Fuel Cells", *J. of Aerospace Eng.*, 2011, Vol. 24, pp. 79–88, ISSN: 0893–1321.

About the Authors

Professor Giulio Romeo, Full Professor of Airplane Design and Aerospace Structures
Fabio Borello, PhD
Gabriel Correa, PhD
Politecnico di Torino – Department of Mechanical and Aerospace Engineering
C. Duca degli Abruzzi 24
10129 – Torino (Italy)
giulio.romeo@polito.it
fabio.borello@polito.it
gabriel.correa@polito.it
www.polito.it/grupporomeo

Introduction to Part Three
National and International Programmes

In Part Three, the book provides papers giving an overview of national and international aeronautics activities, first on initiatives within the framework of the ERA (European Research Area), and second on examples for international cooperation initiatives.

Within the framework of ERA, three types of activities are approached:

- National RTD Support for Aeronautics (France, Germany, UK, Spain, Austria and Sweden);
- European Aeronautics Networks (IFAR, ACARE, GARTEUR, EASN);
- Support Initiatives (Poles of Competitiveness, Education).

Two examples of international cooperation initiatives are presented:

- Russian Aeronautics Research Programme;
- Latin America – EU.

This page intentionally left blank

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-415

"CORAC": The Concerted Approach of French National Council for Civil Aviation

Patrice DESVALLÉES

Abstract. The French Council "CORAC" has been created in the wake of the "Grenelle de l'Environnement", France's environmental round table process, with a large consultation involving all sectors. It was launched in July 2007 and ended three months later, in October. Concerning aviation, it was recommended in particular to increase research and technology development efforts and support to innovation, key-drivers to the "greening" of future civil aviation.

Keywords. Grenelle process, CORAC, French RTD support

1. Introduction

Following the Grenelle process, all French civil aviation stakeholders signed up to an agreement in January 2008 with Mr. Borloo, Minister for Energy, Transport and Sustainable Development. After a preparatory phase, CORAC was then officially launched in July 2008 by Mr. Bussereau, Minister for Transport. This council is aiming for "greener" aviation, in line with the ambitious European ACARE environmental 2020 goals:

- Cutting CO_2 emissions by 50%;
- Reducing NO_X by 80%;
- Reducing perceived noise levels by 50%.

Under the chairmanship of the Minister for Transport, CORAC gathers together all the French stakeholders in Civil Aeronautics and Air Transport at the upper level (i.e. CEO or chairman level). These stakeholders include representatives from aircraft, engine, system and equipment suppliers, Airlines, Airports, Air Navigation Service Pro-

viders (ANSP), Institutions & professional associations, as well as ONERA and all Ministries concerned with aeronautics and aviation research: Ministries of: Research, Industry and Finance, Defence, Ecology and Transport.

CORAC is a national forum which allows a concerted approach to better coordinate and optimise aeronautics research efforts to foster aviation technology breakthroughs and innovations toward the European ACARE ambitious environmental objectives set for 2020, and extended to 2050 (Vision "Flightpath 2050" revealed by Commissioners Kallas and Maire Goeghegan – Quinn during the AERODAYS2011 Conference). The new vision's quantified environmental 2050 goals include the following:

- Cutting CO_2 emissions by 75%;
- Reducing NO_X by 90%;
- Reducing perceived noise levels by 65%.

The CORAC council's working structure includes in particular:

- A Steering Committee;
- 5 Working groups and committees;
- A Communications office.

Wide consultation is a key to the functioning of the CORAC council. The work is based on large consultations, information exchanges, knowledge sharing and transparency between all French aviation stakeholders.

On environmental topics, CORAC identifies key issues and ensures specific outcomes, for example, from specialized sectors a strengthening of studies and research aiming at comprehension and modelling of the impact of air transport on the environment and climate change mechanisms. Examples of the priority topics identified include: combustion products, climate impact, noise propagation, and pollution chemistry modelling in the airport environment.

CORAC is open to representation from organisations beyond the direct aeronautical community (external specialists are consulted whenever needed, e.g. climate change, meteorology, etc. …)

Fully in line and coherent with ACARE strategy and European activities (FP collaborative research, JTI, etc.), CORAC defines roadmaps for R&T efforts with a commitment from its members to take measures for their concerted implementation of them.

2. The Virtue of National "ACARE" Mirror-Platforms Is to Be Continued

Like CORAC in France, in Europe close to fifteen ACARE-like national mirror-organisations have been set up in Europe (Fig. 1).

Facing ever-greater traditional and emerging competition from countries displaying new major aeronautical ambitions, the technology leadership of European aviation, particularly with respect to "Greening" is key and has to be maintained in the future. The best practices and initiatives developed over the last decades by European aviation stakeholders in terms of aviation RTD Vision 2020, ACARE, agenda SRA 2020 (now "Flightpath 2050"), and European national and regional coordination are truly virtuous dynamics which are essential to pursue in the future.

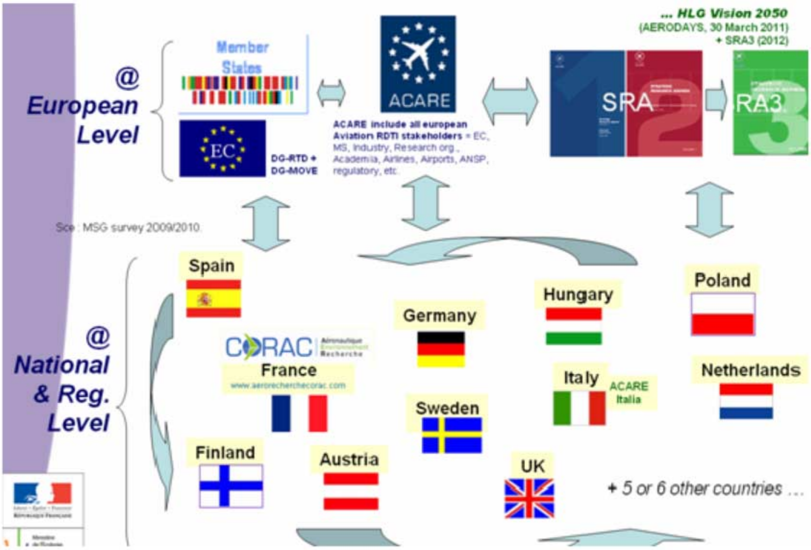


Figure 1. ACARE like mirror organisation within Europe.

It is therefore essential for Europe to continue to work together towards the preparation of the future of aviation, along the new and ambitious "Flightpath 2050" goals.

About the Author

Patrice Desvallées – Deputy Director for Aeronautics
Directorate General of Civil Aviation (DGAC)
50, rue Henry Farman
F-75720 Paris
patrice.desvallees@aviation-civile.gouv.fr
www.aviation-civile.gouv.fr

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-418

The German National Aeronautics RTD Programme

Franz-Josef MATHY

Abstract. The aim of this paper is to give an overview over "LuFo", the civil Aeronautics RTD Programme of the Federal Government of Germany, and similar activities of the German Länder. LuFo was established in 1994, to back up the technological preparation for actual aircraft programmes in the civil sector. Since then, a significant number of calls have been launched. In the frame of the actual programme line, LuFo IV, annual spending has increased to more than €100 million.

Keywords. LuFo, German RTD support

1. LuFo as Part of the German High-Tech Strategy

Today, LuFo is part of the German High Tech Strategy. This was developed and adopted by the German government in analogy to similar activities in other export-oriented countries. The goal of the High Tech Strategy is to strengthen the global competitiveness of key forward-looking sectors and global technical leadership of key technologies. For this reason, instruments on regional and national level have been implemented that aim to enable and foster research activities by private companies, research organizations and universities.

By investing more than 6 bn Euros of additional funding in technological RTD-activities the High Tech Strategy substantially contributes to the target benchmark of R&D spending on a 3% GDP level. The major part of the funding within the scope of the High Tech Strategy is provided by the Federal Government. Plans for the current financial period that runs from 2011 to 2013 also include further spending on this high level.

Several distinct characteristics qualify aeronautics as one of the core elements of the German High-Tech Strategy:

Firstly, aeronautics and aeronautical research provide a great impetus for many technological developments in other industries and also serve as a gateway to key horizontal technologies. Mainly for these reasons, the aeronautics industry owns a status as a strategic sector for the whole economy.

Secondly, the aeronautics sector plays a major role on the way to a sustainable and eco-efficient air transport system. Air transport with its specific characteristics and capabilities must be seen as an integral part of a mobility concept for the future. Especially for export oriented economies that are deeply integrated in global work sharing air transport plays a prominent and indispensable role. As sustainable mobility is one of

the major societal challenges to be addressed, aeronautics research is consequently at the heart of the High Tech Strategy as well in this respect.

Apart from spill over effects and the contribution of aeronautics to sustainable mobility, the importance of aeronautical research in the light of an intensifying global competition is also recognized by the German government and parliament. In order to keep the industrial leadership by the European aeronautics industry, their efforts in RTD have to be continued on a high level or even increased in the future. Here, the role of the public sector is to provide an international level playing field and fair conditions for competition.

2. LuFo Within a Three-Pillar Strategy of Regional, National and European RTD Strategy Programmes

The aeronautics sector consists of different players that operate on different levels. Besides local and regional players its backbone is formed by industrial players that mainly operate on a European and global level. In the most prominent projects a sizeable number of players located in many different countries have to work together.

As the structure of public research programmes needs to reflect this, the German National Aeronautics RTD- programme is part of a three pillar strategy.

This strategy supposes that the national programme is complemented by the research projects carried out within the framework of the EU Research Framework Programme as well as by programmes ran by individual federal states or regions in Germany where the aeronautics industry plays a particularly important economic or industrial role.

At the European level, the EU programme can foster the creation of transnational networks at a pre-competitive stage. These networks facilitate the pooling of industrial expertise across the entire EU. And this in turn opens up the possibility to integrate complex individual systems into total systems and to test them on larger technology demonstrators.

At the national level, the national aeronautics research programme mainly involves projects that focus on the core expertise of German companies, often in their capacity as partners within European networks.

At the federal state or regional level in turn, the major aim is to enhance cooperation between regional supply chains. For this reason, an increasing priority is being placed on the promotion of clusters and the improvement of research infrastructures.

This three-pillar approach is assessed as very effective structure by the German government. For this reason we are strongly interested in its continuation and, together with other member states, emphatically advocate the implementation of a sector-specific aeronautics programme within the Common Strategic Framework for Research and Innovation.

3. Technical and Thematic Characteristics of LuFo

The allocation of funding generally takes place within the framework of calls and not as part of an ongoing procedure. The selection of projects involves a two-step process. Companies, research institutes and higher education institutions can apply for funding

by submitting a project outline. Independent experts then conduct a project appraisal based on this outline.

In general, funding is not awarded on a first-come, first-served basis. Instead, we provide the experts with a non-binding set of categories based on the growing competences and capabilities of our national industry. Categories within this set are propulsion, flight physics, structure, cabins/systems, traffic management and helicopters.

From the beginning, the programme has always had the ambition to strengthen the aeronautical research network in Germany, consisting of the industry, SMEs, universities and research institutes. To be transformed into successful marketable and competitive products, research in aeronautics generally needs to be industry-driven. On the other side, German research institutes as DLR and Fraunhofer as well as a number of (technical) universities specialized in the area provide research facilities that are excellent on an international level. The aim of LuFo is to bring industrial needs and scientific excellence together in order to exploit synergies optimally. For this reason, the formation of powerful networks and a realistic market perspective are essential criteria in the evaluation of submitted proposals.

The idea of strong networks consisting of all stakeholders is also mirrored by funding conditions. In line with EU state aid regulations, grants are given that cover 40% of the project costs in case of industrial companies, 50% in case of SMEs while universities and research centers get 100% funding of project costs. Additionally, a 10% incentive bonus can be achieved for industry or SMEs if they include universities or research centers as subcontractors in their research projects.

The thematic content of the aeronautics research programme is closely aligned with the priorities of the respective ACARE Strategic Research Agenda. Within this frame, a clear focus is put on the interests and key areas of our national industry as well as on its work packages within the Airbus- and other international programmes.

However, as purchasing strategies of the OEMs are becoming more and more global in scope, one of the key aims of present calls is also to boost the independence of suppliers in their relations with non-European OEMs.

According to the ACARE goals, the major focus of LuFo topics is on efficiency and sustainability of the air transport system.

Societal acceptance of air transport in the mid-term will crucially depend on substantial achievements towards an environmental friendlier technology. Amongst others, innovative concepts for air frames and engines are key factors to reach this target. However, due to a high level of sophistication and complexity in these technological areas, innovations can only be found with huge efforts. In order to support the efforts, LuFo has a defined the areas mentioned above as main research topics. This leads to a total share of around 80% of the LuFo-budget relating to topics in the scope of sustainability and efficiency. With this, the priorities of the different LuFo calls are perfectly in line with the overarching technological objectives of the ACARE strategy.

One example of a technological focus of the current call that is linked to a "greener" air transport system is the area of innovative production processes and operations using carbon fibre composite constructions. In this field further progress is strongly needed in order to make those technologies affordable in terms of production costs. Only if this condition is met, this technology that allows for substantial weight reductions in aerostructures will be established in the long run.

About the Author

Franz-Josef Mathy
Head of Department Aerospace Industry
German Federal Ministry of Economics and Technology
Scharnhorststrasse 34-37
D-10115 Berlin (Germany)
Tel.:+49 30 18615 7471
mathy@bmwi.bund.de
www.bmwi.bund.de

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-422

The UK National Aeronautics Technology Strategy

Ray KINGCOMBE

Abstract. The UK National Aerospace Technology Strategy (NATS) articulates the required technology development and technology demonstration programmes required to maintain UK competitiveness and position in the global industry. The UK's aims are entirely compatible with those stated in the European Vision 2020 "Meeting society's needs and winning global leadership". NATS ensures that UK national and EU Framework funding is used in a fully complementary fashion. A UK Aerospace Technology Steering Group (ATSG) was formed and has coordinated this strategy to identify areas where the UK could compete globally: roadmaps of the major programmes required to meet future market needs have been produced, covering airframes, engines, equipment, rotorcraft, ATM and autonomy. Activity has taken place in all areas.

Keywords. Technology strategy, UK

1. The Aerospace Industry in the UK

The Aerospace Industry in the UK is the largest in the world after the US and is a crown jewel in the UK manufacturing sector. The UK has 17% of the global market share, supporting over 100,000 direct high-skilled jobs and 70% of the production is exported. Hence the sector is an asset for the UK as a whole. The UK has significant involvement on major civil and military programmes through Airbus, Bombardier, Boeing, Eurofighter and the Joint Strike Fighter. The UK strategy in the civil field is based around being the global centre of excellence for wings, engines, equipment and rotorcraft. The UK designs and integrates all the wings for Airbus aircraft including the A320, A330/340, A380, A350XWB, A400M and now A320NEO. The UK also designs and manufactures a whole range of large civil engines, the whole Trent family (600, 700, 800, 900, 1000 and XWB).

2. Future Threats and Opportunities

Looking to the future the market for civil aircraft is predicted to continue to grow globally, with traffic set to double in the next 20 years. The market for the next new single aisle aircraft (to replace A320 and B737 families) alone is predicted to be $2.6 trillion. This may not enter into service until 2025 but in the interim there are also significant opportunities on the A320NEO, B737MAX, A350XWB variants, B777 variants and civil rotorcraft. The potential emergence in the future of UAV's could also present significant opportunities. However this growth is set in the global context of increasing competition for high value work, particularly from the Far East but also from Brazil

and Russia. This is overlaid with the emergence of new technologies in composite materials and open rotor engines.

Aerospace programmes have individual characteristics not found in other manufacturing sectors. Programmes for new aircraft are very infrequent and becoming even more spaced out. Airline customers demand substantial operating and cost improvements between generations to justify their investment. Development time for new aircraft is long and costly (over £10 billion), not only because of the complex systems involved but also to satisfy necessary safety and certification criteria. Aircraft have long service lives – now over 30 years.

Hence for primes and suppliers there is infrequent opportunity to get on to new programmes, and missing out on participation in one step can make it very difficult for the business to survive until the next. There are also major technology steps between generations and a need to maintain differentiated capabilities.

3. Aerospace Growth in the UK

The Vision for aeronautics in the UK is that by 2022 the UK will offer a global Aerospace Industry the world's most innovative and productive location, leading to sustainable growth for all its stakeholders. This involves having proven world-class technological capability as an essential enabler as well as the necessary skills, supply chain relationships, infrastructure and investment. The UK has to stay world-class in high value advanced technology aspects. A national stakeholder group, with reporting line to Ministers, was formed to sustain a level of focused Aerospace applied research and validation/demonstration sufficient to maintain and enhance the UK's position in the global Aerospace market. Hence the National Aeronautics Technology Strategy (NATS) formed in a partnership of government, industry & academia for a market-led, jointly funded R&T programme.

4. The National Aeronautics Technology Strategy

The joint activity with industry, government (civil and defence) and academia identified civil & military technology themes where the UK aerospace companies were innovative global aerospace leaders or could become such, covering airframes (particularly wings), engines, equipment (e.g. landing gear, fuel systems, aircraft power systems, control systems, …), rotorcraft and autonomous systems. With the emphasis on exploitation of technological capability the 'blue sky' university-only programmes are not in scope.

A common view of the future market with specific product opportunities was formed, including timescales. This was the basis for identifying the major technology demonstration/validation programmes that would be required to meet these future product needs, including when the results would be needed and hence when the work should start. Roadmaps were formed of these major programmes. The airframe and power plant parts of the roadmap are shown (Fig. 1). Above this would be a view of the future market and products (not shown). In addition there are further roadmaps on equipment, rotorcraft and autonomous systems.

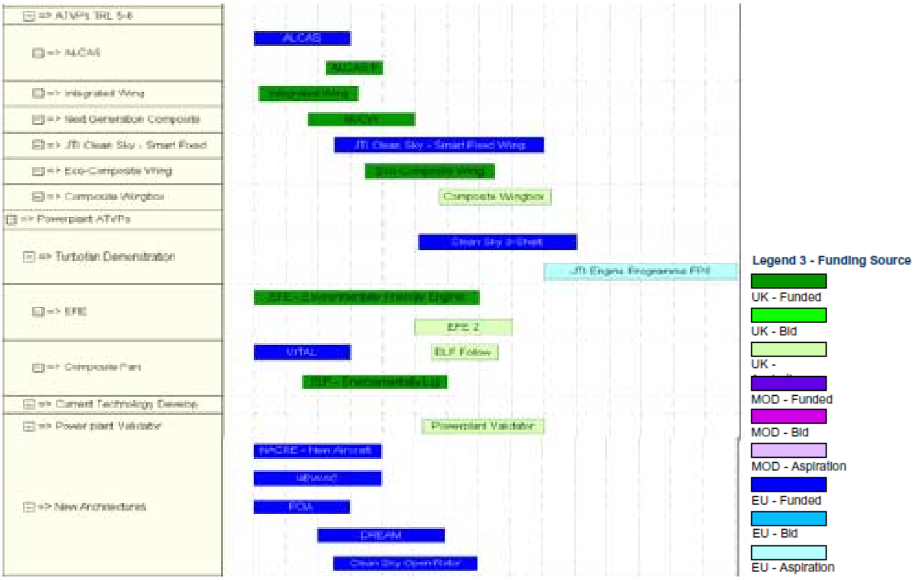


Figure 1. Example of technology roadmap: Airframe and Power plant.

At a lower maturity level than the technology demonstrators, the technology development needs are discussed and added to the roadmaps through 13 individual National Technology Committees in particular technologies e.g. fluid dynamics, materials & structures, electronic systems or human factors. This helps with the NATS objective to embed technology throughout the supply chain as a basis for future product development.

Each major programme was also associated with a target funding source. The source depends on how collaborative the work could be and how close some aspects were to commercial confidentiality. The major sources of government funding identified were civil/industrial research (through the Technology Strategy Board), defence and EU Framework. This is an important aspect because it ensures complementarity between the various funding sources adding coherence to military and civil aerospace programmes. Often, but not always, early stage technology exploration can occur in wide collaborative programmes with either EU or national funding. Programmes then often become more commercially sensitive as the particular application of the technology is developed. This stage is usually done with national funding or even by companies with their own funding. The next stage of technology system demonstration or validation can then be done in large collaborative programmes such as EU Framework Level 2 programmes where the participants work together but need only disclose the interface aspects of their participation in the demonstration, not the 'internal' details of how it is achieved in their component. Hence overall gaps and overlaps between national and European funding sources can clearly be avoided.

NATS is overseen by an Aerospace Technology Steering Group (ATSG) with representation from all stakeholders. This group had a reporting line to BIS Ministers which is evolving following the election of the new government in the UK. There is an Aerospace Business Leaders meeting chaired by the Secretary of State and a broader Aerospace Growth Partnership Group chaired by the Minister for Business which has a

specific technology sub-group. The Aerospace Aviation and Defence Knowledge Transfer Network (KTN) holds the strategy and facilitates ATSG. However it should be noted that any lobbying cannot be done by the KTN.

5. What Has Been Achieved so Far?

Firstly and importantly significant advances in validated technology have been achieved in all areas, e.g. composites technology, combustion/emissions technology including major test rigs, etc.: the UK has retained No2 spot in world. The national implementation of NATS has brought together the national and regional sources of funding, establishing a partnership between the Technology Strategy Board, English Regional Development Agencies and Devolved Administrations in Wales, Scotland & Northern Ireland with UK companies. There has been significant investment by industry & government in NATS with over £400M government investment in the first 6 years – 2004 to date. The programme has also ensured coherence in use of UK national and EU funding.

6. Future Outlook

The content of the Strategy continues to be refreshed periodically. But there are aspects of NATS which continue to evolve. The multiple national and regional funding sources for large projects have made the funding process complex. The coordination of low maturity research through the National Technical Committees is a complicated process with many organisations involved. NATS has not gripped the issue of aerospace research infrastructure in the UK which needs further attention. Overall the issue from industry of affordability of the programme with continued access to government funding remains an ongoing issue. In this respect the role of the recently established Technology Innovation Centres in the UK could be a useful development.

7. Conclusion

The UK has the opportunity to retain significant market share on future global aerospace programmes. Technological capability is a significant enabler and there is a need for continued support for aerospace research and technology to enhance UK capability in world-class areas of airframes/wings, engines, equipment and rotorcraft. Large projects deliver major systems integration and validation benefits for the primes and supply chain and there is a coordinated and coherent programme using UK and European funding sources. This has set the UK in a good position for the future.

About the Author

Dr Ray Kingcombe – Head of Technology
Aerospace, Marine & Defence Unit -Department for Business, Innovation & Skills (BIS)
1 Victoria Street – London SW1H 0ET, UK
Tel.:+44 207 215 1115
ray.kingcombe@bis.gsi.gov.uk, www.bis.gsi.gov.uk

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-426

RTD Support for Aeronautics in Spain – CDTI

Juan Carlos CORTÉS PULIDO

Abstract. The Centre for the Development of Industrial Technology (CDTI) is a Spanish public organisation, under the Ministry of Science and Innovation, whose objective is to help Spanish companies to increase their technological profile. CDTI has become a key organisation for the promotion of innovation and technology development in Spain, since its creation in 1977.

Keywords. Spanish ministry science and innovation, CDTI

1. The Mission of CDTI

The mission of CDTI is to help Spanish companies in several points:

- Improving their technological level profile by providing funding for research and development projects;
- Managing and promoting their participation in international technological co-operation programmes;
- Facilitating technology transfer.

CDTI also encourages and assists in the creation, development and consolidation of technology-based companies in Spain (Fig. 1).

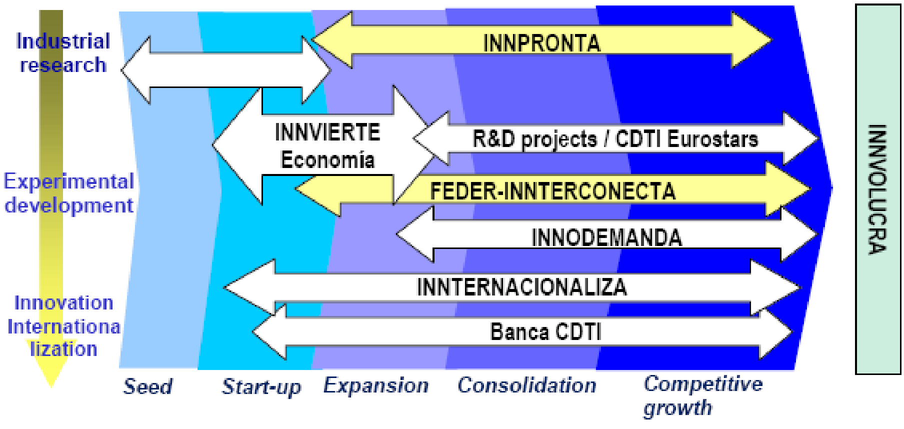


Figure 1. CDTI will boost all enterprise innovative activities with most adequate instrument (capital, grants or loans with a non-returnable part).

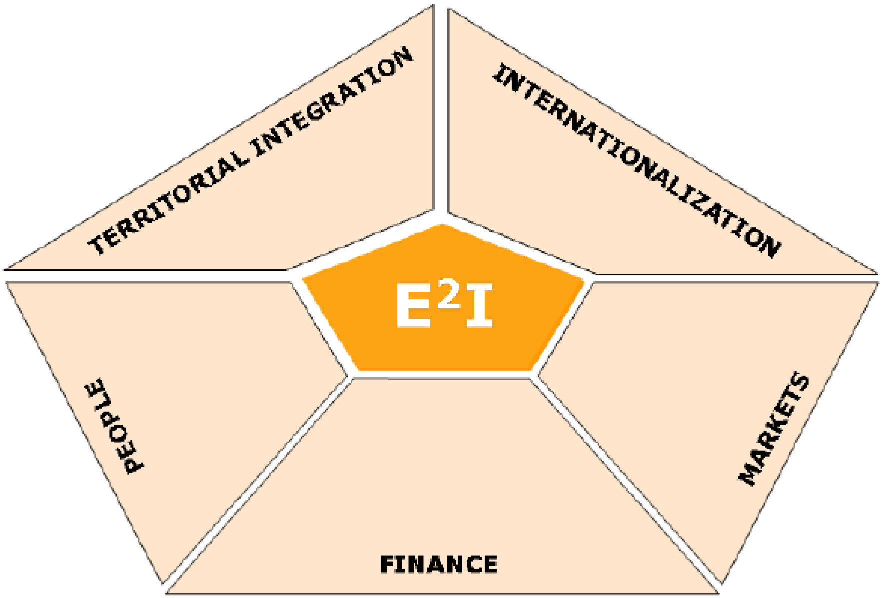


Figure 2. The Spanish Innovation Strategy E2I.

The action of CDTI is aligned with the State Innovation Strategy (E2i) of the Spanish Ministry of Science and Innovation. This is the Spanish government political framework for action in the field of innovation to help change the production model in Spain, through the promotion and creation of structures that facilitate a better use of scientific knowledge and technological development. The E2i is a multisectorial project involving all innovation stakeholders. It encompasses fives axes: International projection, Public Demand, Financial framework, Human Capital and Regional cooperation (Fig. 2).

CDTI is one of the key managers of the Spanish national aeronautics RTD programmes with the main objective to increase competitiveness and technical excellence in order to generate higher levels of sustainable growth and productivity in the national economy. The overall objectives of the programme are in line with the vision 2020 of EU and with the ACARE Strategic Agenda: reduce the impact on the environment, increase the security and safety, increase the interoperability of ATM systems, operating and life-cycle cost reductions, stretching niches of excellence and quality etc.

The mentioned objectives have been adopted in the Strategic Aerospace Research Agenda of the Spanish Aerospace Platform (PAE). This platform was created with the objective of becoming established as the reference body for the Spanish sector with regards to the needs and strategies of the aerospace activities, as a mirror platform of European ACARE. To reach these objectives, especially RTD projects and technology demonstrations proposed by industry, CDTI encourages and fosters the participation of Spanish companies in projects focus on strategic fields such as unmanned aircrafts, composites, new materials, ATM systems, engines etc (Fig. 3).

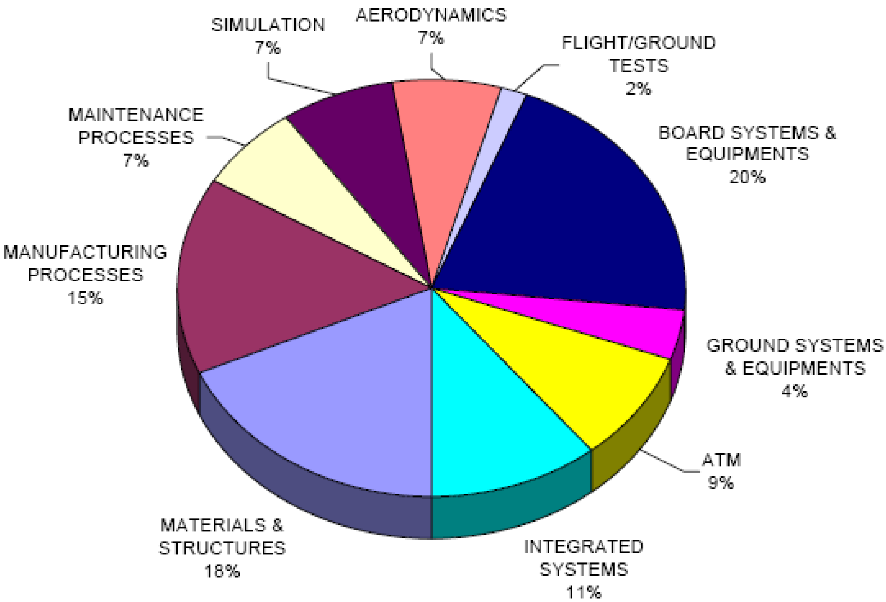


Figure 3. AERONAUTICS thematic areas Vs national R&D funded projects between 2006–2010.

About the Author

Juan Carlos Cortés Pulido
Director of Global Innovative Markets
Centre for the Development of Industrial Technology (CDTI)
Cid, 4
28001 Madrid (Spain)
Tel.:+34 91 581 0707
juancarlos.cortes@cdti.es
www.cdti.es

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-429

Austrian R&D Strategy and Initiatives for the Aeronautics Sector

Elisabeth OSSBERGER

Abstract. "TAKE-OFF", the RTD-programme for Aeronautics, which was launched in 2002, got adapted to the articulated goals: target groups and instruments were enlarged and the market segments were implemented in the content of the calls. SMEs got strong support and international networking got more emphasis by the programme owners. Actual emphasis is put on networking activities within the market segments and on the international level; within "AirTN", Austria launched a trans-national call together with Germany, and thus three important projects have been funded. Austrian companies as well as universities participate as partners in FP7, Clean Sky and SESAR. This paper gives an overview of these activities on a national level.

Keywords. Austrian RTD programme, Take-Off programme

1. The Austrian Aeronautics Industry

Austria has great ambitions to support the aeronautics sector and to be a key actor with high end technologies within the supply chain. The Austrian Aeronautics Industry mainly consists of a supply chain industry, but a few of the companies are primes like Diamond Aircraft or Schiebel. A study funded by our ministry, looking to the numbers of this sector in Austria, gave the following results: 240 companies have been identified being active in aeronautics with a turnover of 1.4 bn € in 2008 and more than 7,404 employees; 13% of them were employed in research and development. The share of market segments of those companies is shown in Fig. 1. Mostly they are active in complex aircraft structures and components, cabin equipment and aircraft electronics.

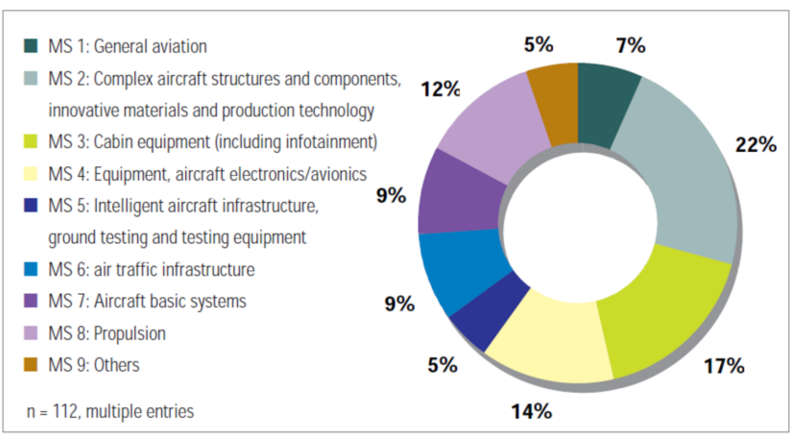


Figure 1. Market Segments of the Austrian Aeronautics Industry, Brimatech 2009.

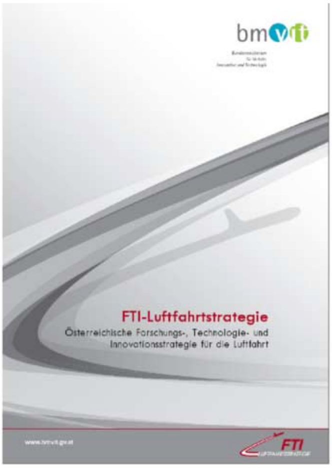


Figure 2. Brochure of the Austrian Aviation Strategy for Research, Technology and Innovation, bmvit 2008.

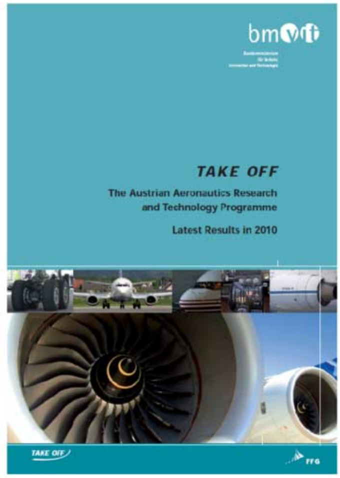


Figure 3. Brochure of TAKE OFF, the Austrian Aeronautics Research and Technology Programme, bmvit 2010.

In 2008 the Federal Ministry for Transport, Innovation and Technology (bmvit) published a strategy for research, technology and innovation for aeronautics. A stakeholder process has been therefore initiated, in which the industry, science, administration and aviation sectors are involved. Austria therefore adopted the main goals of the Strategic Research Agenda of ACARE, the Advisory Council for Aeronautics Research in Europe, which was published in 2004. Following the definition of international technological trends and market dynamics, the Austrian players and competences have been identified and scenarios of the Austrian potential of market growth in this field have been drawn. In the end, a vision for the aeronautics sector with achievable goals has been created, and measures for the realization of this strategy have been formulated.

2. The "Take Off" Programme

TAKE OFF – the Austrian RTD-programme for aeronautics, which was launched in 2002 – got adapted to the articulated goals of the strategy: target groups and instruments were enlarged and the market segments of the strategy were implemented in the content of the calls. SMEs got stronger support and international networking got more emphasis by the programme owners. So up to now, M€ 49,5 have been invested into this programme and 124 projects have started. The huge consortiums also with partners and primes from foreign countries proved to be a success. Interesting results have been achieved.

As a supporting measure for more transparency, a screening of the Austrian aeronautics sector was made in 2009. In total, 240 companies were found to be working on aeronautics in Austria. This was a very surprising result for experts as well, and in the end a brochure of Austrian competencies in Aeronautics was produced. It was also published as web-based data-link: www.aeronautics.at

Figure 4. Catalogue of the Aeronautics Industry in Austria, bmvit 2010.

Actual emphasis is put more on networking activities within the market segments and on the international level. Within "AirTN" Austria launched a trans-national call e.g. together with Germany and three projects worth M€ 35.7 have been funded. Austrian companies as well as universities also participate as reliable partners in FP7 and in Clean Sky and SESAR.

With the mentioned activities Austria wants to support the very active and successful Austrian aeronautics industry to get more competitive, especially on the global level.

About the Author

Mrs. Elisabeth Ossberger
Aeronautics Research and Innovation Manager
Austrian Federal Ministry for Transport, Innovation and Technology – Department Mobility and Transport Technologies
BMVIT
Renngasse 5
1010 Vienna (Austria)
Elisabeth.Ossberger@bmvit.gv.at
www.bmvit.gv.at

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-432

Sweden – Aeronautics RTD Programme and Research Agenda

Gunnar HULT and Vilgot CLAESSON

Abstract. The Aeronautics RTD programme in Sweden was in the past dominated by the needs for the development of military aircraft and this programme is still continued to support the Gripen but with a lower level of effort. The national Aeronautical Programme (NFFP) started in 1994 and is now in its fifth phase (2009-2012). Its objectives are to: (i) strengthen Swedish competitiveness; (ii) strengthen the capability to participate in international research cooperation; (iii) support Swedish Armed Forces.

Keywords. Sweden RTD, Gripen

1. Aeronautics in Sweden

Sweden has a traditionally strong and competitive aviation industry and aviation expertise. In the past the nation has been quite successful in developing civil and military products. Some key accomplishments in the past are:

- First swept-wing fighter in Europe – J29 in 1948;
- First double-delta-wing aircraft – J35 in 1955;
- First canard-wing jet fighter – AJ37 in 1967;
- First JAA/FAA jointly certified airliner – Saab 340 in 1984;
- First fourth generation fighter – JAS 39 in 1988.

Behind this success, close R&TD collaboration between users, industry, academia and agencies as well as an integrated civil-military aeronautics research community are important contributing factors. International cooperation has always been a strong element and over the past 20 years Swedish aeronautics has been strongly involved in European R&TD programmes.

Today the Swedish aeronautical sector employs over 10,000 persons, subcontractors excluded, and has a turnover of more the 2 billion EURO per year with a growing export share.

The main companies are Saab and Volvo Aero. The Gripen fighter is now in operation with five Air Forces worldwide and about 500 Saab 340/2000 commuter aircraft are in operation worldwide. Volvo Aero has been very successful in the transformation from military to civil production and today 90 % of large civil aircraft engines have components from Volvo Aero.


J29 Flying Barrel


J35 Dragon


JAS39 Gripen

Saab 340


JAS39 Gripen


Saab340 with AEW radar

2. Aeronautics Research & Technology Programmes

The R&T programme in the past was dominated by the needs for the development of military aircraft, and this programme is still continued to support the Gripen programme but with a lower level effort.

Since the early 1990-s a research programme with joint civil and military funding has been established – the National Aeronautical Programme (NFFP), which is the focus for this presentation. In addition a programme to support the technology demonstration "Aeronautical Development and Demonstration Programme (FLUD)" has been running 2006–2010.

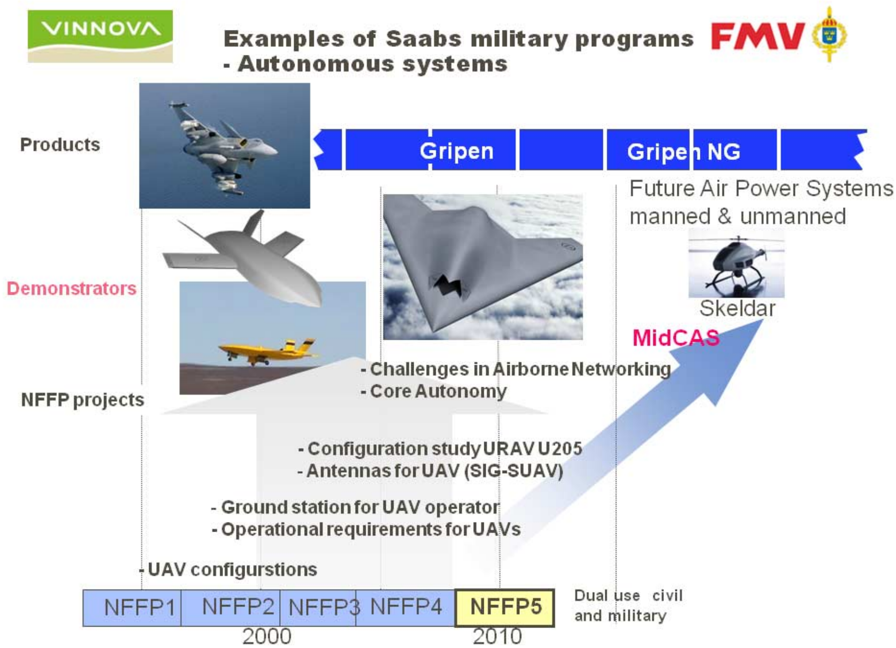
3. The National Aeronautical Programme (NFFP)

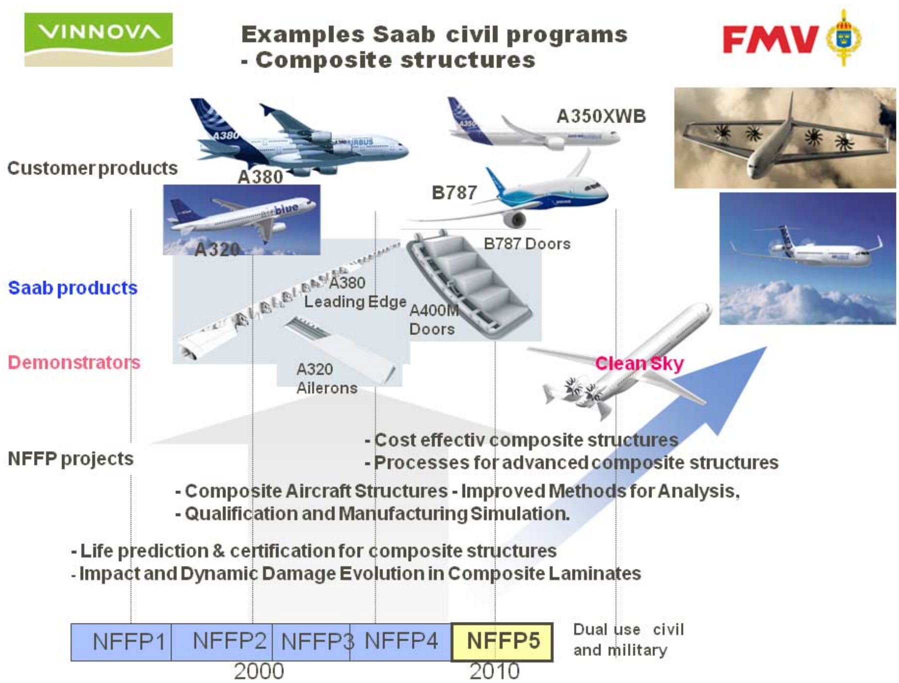
The NFFP programme started in 1994 and is now in its 5th phase (2009–2012). The annual volume is about 12 Million EURO with 50% public funding and 50% industry funding. The public funding is spent for research performed at universities, research institutes and SMEs.

The NFFP objectives are to:

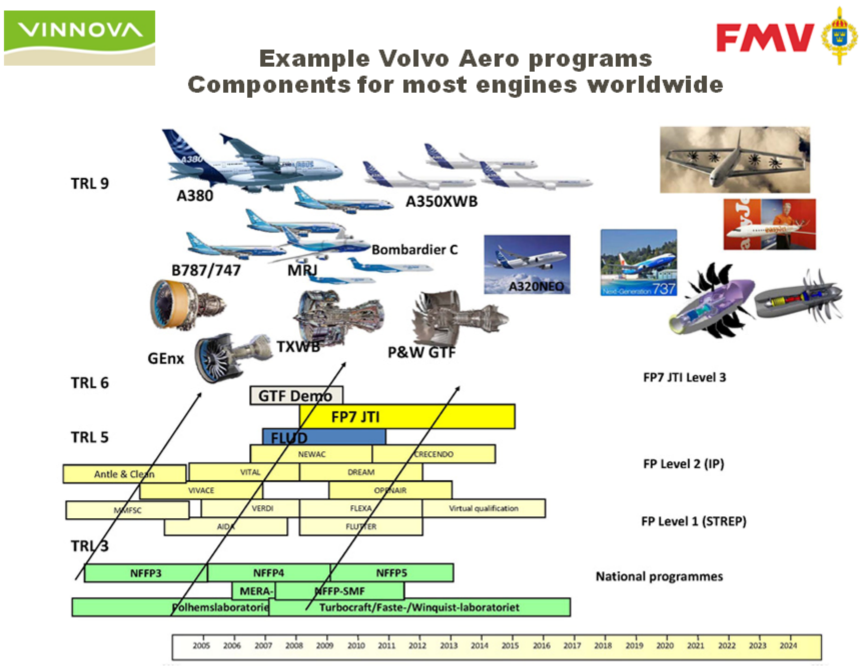
- Strengthen Swedish competitiveness in aeronautics;
- Strengthen the capability to participate and learn from international research and technology cooperation;
- Support Swedish Armed Forces by building and maintaining knowledge for systems operation and development.

The projects performed within NFFP are on lower TRLs with the aim to build basic knowledge which is then applied in many European R&T projects and demonstrator programmes as illustrated in the following pictures:





For Saab a military example is Autonomous systems, where Saab is a partner in Neuron. The example on the civil side is composite structures, where Saab is a subcontractor on ailerons, leading edges and doors for Airbus and Boeing.



Volvo Aero is a subcontractor to most aircraft engine programs worldwide, and today 90 % of large civil aircraft engines have components from Volvo Aero.

4. The National Research Agenda – NRA Flyg 2010

In a joint effort by all stakeholders a National Research Agenda has recently been developed with the following aims:

- Achieve a broad consensus on aeronautics research;
- Strengthen aeronautical research funding;
- Constitute a basis for decisions about research directions;
- Align Swedish aeronautics research with ACARE goals;
- Support international positioning.

The document was published in 2010, and identifies goals, prioritises technical areas and formulates recommendations that will benefit Swedish aerospace industry. National research and demonstrator programmes are also proposed as follows:

- NFFP 6 – a continuation of NFFP 5;
- Triple use – focusing on joint development between civil aerospace, military aerospace and other industries;
- Green and sustainable demos – for supporting participation in international civil demonstrators;
- Military demos – international military demonstrators in EU and transatlantic partnerships.

About the Authors

Gunnar Hult
FMV – Defence Material Administration
SE-11588 Stockholm (Sweden)
gunnar.hult@fmv.se

Vilgot Claesson
VINNOVA – Swedish Governmental Agency for Innovation Systems
SE-101 58 Stockholm (Sweden)
vilgot.claesson@VINNOVA.se

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-437

IFAR – International Forum for Aviation Research

Joachim SZODRUCH and Richard DEGENHARDT

Abstract. The future challenges of air transport motivated in 2010 the leading worldwide aviation research institutions to found IFAR – the International Forum for Aviation Research – which is working on a voluntary, non-binding basis. The primary purpose of IFAR is to connect research organisations worldwide, to enable the information exchange on aviation research activities between members, to facilitate opportunities for networking and creating partnerships and to coordinate views and make recommendations for use by its members. Climate change is currently one of the most relevant topic and was the initial motivation to set up IFAR. However, the focus of IFAR is on all non-competitive research and development topics related to global technical challenges such as those pertaining to emission, noise, security, safety and efficient operations, and steps to reduce the impact of aviation on climate and the environment. Against this background, IFAR aims at developing a regularly updated IFAR Framework Document outlining global research objectives and technological opportunities for use by its members. The results will be updated regularly at the website www.ifar.aero From the beginning, the IFAR activities were supported by the IFAR secretariat which was established and financed by DLR. From mid 2011 the IFAR administration and the IFAR activities are also supported by the 3-year Support-Action-Project IFARs funded by the European Commission. After mid 2014 IFAR is expected and will be self organised without any further external support.

Keywords. Forum, networking, information exchange, communication, cooperation

1. State of the Art/Background

The increasing need for international mobility in a globalised, work-sharing based economy leads to a worldwide growth in air traffic by about 5% per year. This is the basis for economical growth but has an influence also on the climate change which is currently discussed worldwide by scientists, decision-makers and the public. The 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) has stirred an intensive public debate also on future aeronautical research challenges and policies. This report identifies aviation to contribute 2–3% of today's total global anthropogenic CO_2 emissions. This prompted the International Air Transport Association (IATA) to set the long-term challenge of Zero Emission Aviation by 2050 and emphasised the importance of addressing these challenges on a global level. The answers and solutions to these demands are expected to be given by research, eventually industry and operators. Except Member States or regional networks (e.g. EASN or EREA in Europe), specifically non-profit aviation research organisations were up to 2010 not organised on a worldwide level and did not have a representation which can react to global questions and demands. The new International Forum for Aviation Research (IFAR) fills this gap.

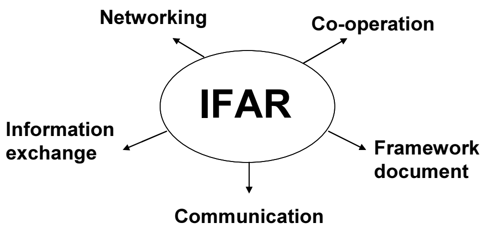


Figure 1. IFAR objectives.

2. Objectives and Results

IFAR aims to realise the following activities (Fig. 1):

- Connecting the global aviation research community worldwide;
- Serving as a venue for information exchange and communication, e.g. by its Summits, by conducting specialist meetings, holding workshops, supporting actively conferences, hosting internet forums, etc.;
- Developing among its members a shared understanding on a common set of key challenges faced by the global aviation research community;
- Developing views and recommendations, e.g. the IFAR Framework Document, to inform on future research strategies and – where appropriate – to develop a combined research strategy for the future;
- Publishing and disseminating information (e.g. via webpage, flyers, publications, participation to conferences);
- Issuing IFAR views and recommendations and give advice on aviation topics; the purpose of issuing such views and recommendations is to define trends in aeronautics research and/or inform legislators concerning emerging regulations; however, views and recommendations are not meant as binding guidance to individual IFAR members and their home country.

3. IFAR Organisation/Members

IFAR operates on the basis of consensus among its members. Annually, principals from IFAR members convene at an IFAR Summit meeting. This event sets the IFAR goals and activities for the coming year and may establish special temporary committees or technical expert groups for IFAR activities of high interest.

Membership in IFAR is open to national aviation research organisations, including universities active in aviation research, which are non-profit and which are owned or mainly publicly funded by governments and which are charged by the country or countries in which they are located to conduct such research activities on their behalf. One organisation per country is accepted for membership.

Current IFAR members are listed in the Table 1 above and are visualised in Fig. 2. These members represent more than 34,000 researchers working in mostly civil aviation. Not counted yet are researchers of IFAR member countries belonging to different research organisations or universities. However, the ultimate aim is that IFAR members represent their countries entire research workforce.

Table 1. IFAR Memebers

	Organisation name	Country
1	Commonwealth Scientific and Industrial Research Organisation	Australia
2	Budapest University of Technology and Economics	Hungary
3	Central Aerohydrodynamics Institute of Russia (TsAGI)	Russia
4	Centro Italiano Ricerche Aerospaziali (CIRA)	Italy
5	Chinese Aeronautical Establishment (CAE)	China
6	Czech VZLU-Aeronautical Research and Test Institute	Czech Republic
7	French Aerospace Lab (ONERA)	France
8	German Aerospace Center (DLR)	Germany
9	CSIR-National Aerospace Laboratories (CSIR-NAL)	India
10	Institute for Aerospace Research (NRC)	Canada
11	Japan Aerospace Exploration Agency (JAXA)	Japan
12	Korea Aerospace Research Institute (KARI)	Korea
13	Middle East Technical University (METU) Ankara	Turkey
14	National Aerospace Laboratory of the Netherlands (NLR)	Netherlands
15	National Institute of Aerospace Research "Elie Carafoli" of Romania (INCAS)	Romania
16	National Institute of Aerospace Technology of Spain (INTA)	Spain
17	Polish Institute of Aviation (ILOT)	Poland
18	Technical Research Centre of Finland (VTT)	Finland
19	The Swedish Defence Research Agency (FOI)	Sweden
20	U.S. National Aeronautics and Space Administration (NASA)	USA
21	von Karman Institute for Fluid Dynamics (VKI)	Belgium

Figure 2. IFAR Member countries.

4. IFAR History

The Fourth Assessment Report of the International Panel on Climate Change (IPCC) has stirred an intensive public debate on future aeronautical research challenges and policies. As a response, in 2008 key leaders of 12 international aeronautical research organisations met in Berlin to address challenges to future Air Transport in the context of climate change. The second time, in 2010, 16 international aeronautical research organisations met and founded the International Forum for Aviation Research (IFAR) in order to take up work on possible research contributions to the climate and environmental challenges faced by the air transport community and with a view to also address further global aeronautical challenges such as noise, security, safety and efficient operations. In 2011, the 2nd IFAR Summit was held in Paris. The number of IFAR members increased to 21. The participants agreed to a common IFAR Charter. They exchanged their views on the global challenges and agreed to develop the Framework

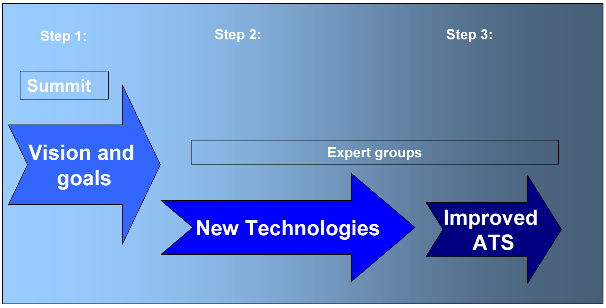


Figure 3. IFAR 3-Step Approach.

document on the technological solutions related to climate impact and noise. Furthermore they started activities on education by promoting and the exchange of graduate students, young scientists and engineers. The next IFAR Summit 2012 will take place in Japan. The IFAR Summits are planned to be regularly every year.

5. IFAR Framework

IFAR aims at developing and maintaining a regularly updated IFAR Framework Document outlining global research objectives and technological opportunities for use by its members. The Framework follows a 3-Step-Approach illustrated in Fig. 3.

1. Step 1 builds the vision and goals which are for instance influenced by political demands;
2. Step 2 considers new and visionary break – through technologies which are expected to fulfil the IFAR vision in Step 1 and which eventually improve the entire Air Transport System (ATS);
3. Step 3. Technologies in this regard are not only software or hardware but can also be improved operations or measures.

IFAR – as research representation – concentrates on the development of the technologies until Technology Readiness Level (TRL) 6. Further qualification and development is expected to be performed by industry. The new technologies do not need necessarily to be developed only within the aviation sector. They can also be transferred from other industrial sectors as automotive, space, energy, etc. Alternative fuels, which might be needed for the future ATS to fulfil the long-term vision can be complementary developed in the energy research sector. Co-operation and research activities across branches and disciplines seem beneficial and mandatory.

The Framework Document may be based on:

- A comparison of existing goals/objectives (cf. [2] to [7]);
- An inventory of possible concepts or technologies which could be developed to accomplish certain objectives.

IFAR can also develop other views and recommendations, findings and reports as may be appropriate. Such documents may include the findings of IFAR Ad Hoc Committees or IFAR Technical Expert Groups.

6. Summary

IFAR is a new International Forum for Aviation Research and was founded in 2010. It connects leading aerospace research organisations worldwide, enables information exchange between them, facilitates opportunities for networking and creating partnerships, coordinates views, makes recommendations and supports students and young scientist/engineers. IFAR focuses on non-competitive topics related to global technical challenges such as those pertaining to emission, noise, security, safety and efficient operations, and steps to reduce the impact of aviation on climate and the environment. IFAR develops a regularly updated Framework Document outlining global research objectives and technological opportunities. The IFAR activities are supported by the IFAR secretariat which was established and financed by DLR. From mid 2011 the IFAR secretariat is also supported by the 3-year EU-project IFARs. After mid 2014 IFAR is expected to be self organised without any external support.

References

[1] www.ifar.aero.
[2] ACARE – Aeronautics and air transport: Beyond Vision 2020 (towards 2050), (June 2010), Available from www.acare4europe.com.
[3] EREA – Vision for the Future – Towards the future generation of Air Transport System, (November 2010), Available from www.erea.org.
[4] Energy Technology Perspectives 2010, Scenarios and Strategies to 2050, International Energy Agency (IEA), Available from www.iea.org.
[5] Flightpath 2050 – Europe's Vision for Aviation, (March 2011), ISBN 978-92-79-19724-6.
[6] IATA – Technology Road Map, 3rd Edition, International Air Transport Association (IATA), (June 2009), Available from www.iata.org.
[7] NASA – National Aeronautics Research and Development Plan, (February 2010), Available from www.nasa.gov.

About the Authors

Dr Joachim Szodruch
German Aerospace Center (DLR)
D-10117 Berlin
E-mail: joachim.szodruch@dlr.de

Dr Richard Degenhardt
German Aerospace Center (DLR)
D-38108 Brunswick
E-mail: Richard.Degenhardt@dlr.de

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-442

Coordination of Aeronautics Interest in the EU Member States

Javier ROMERO and Roland GURÁLY

Abstract. This paper introduces the efforts of the European Member States, obviously in line with ACARE goals, in terms of technology platforms and strategies. In order to better understand the implementation of these goals on national level a survey was launched in 2009 by the ACARE Member States Group. The outcome of this survey is also included in this paper.

Keywords. ACARE, strategic research agenda (SRA), member states group (MSG)

1. Introduction

In January 2001 the Group of Personalities set two ambitious goals for European Aeronautics. An aircraft and air transport system better serving societies needs while becoming a global leader in the field of aeronautics. As a result a report "European Aeronautics: A Vision for 2020" was published.

In this report the Group recommends developing a long-term commitment by all stakeholders (e.g. the aeronautics industry, airlines, airports, air traffic control service providers etc.) to work in closer partnership and on the basis of consensus with the aim of strengthening and reorganising research and development efforts in Europe.

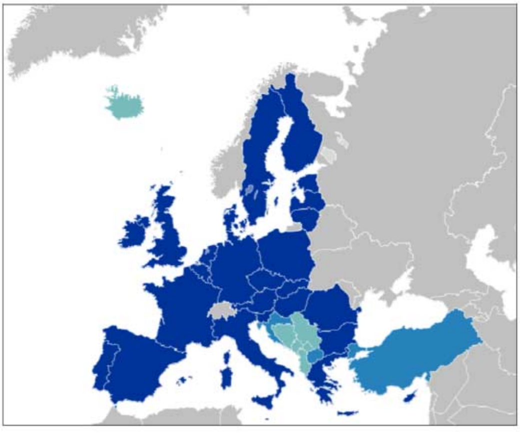


Figure 1. Member States (EU and accession).

Besides these recommendations, the report also concluded that there is a need to create an Advisory Council for Aeronautics Research in Europe (ACARE) to develop and implement a strategic approach to European aeronautics research ACARE's main focus was and will be to establish and carry forward a Strategic Research Agenda (SRA) that will influence all European stakeholders in the planning of research programmes, particularly national and EU programmes as well as private funded research, in line with the Vision 2020 and the goals it identifies. The mission of the Member States Group (MSG) within ACARE is to foster the optimum involvement of Member States in the formation and the implementation of the Strategic Research Agenda for aeronautics in Europe. Besides, this group represents the needs and objectives of the Member States in the work of ACARE.

2. National Research Programmes

As it was mentioned above the ACARE focuses on implementation of the Strategic Research Agendas (SRA from 2002) and its follow-on (SRA2 from 2004). These agendas are built around six major challenges that represented the basis for the aeronautics and air transport research on European level, for many Member States and for the private stakeholders.

For successful implementation of SRA, ACARE activities are likely to include:

- Launch and approve the SRA and update it periodically;
- Make strategic and operational recommendations as well as commission studies for implementing the SRA and achieving the 2020 Vision;
- Evaluate the overall results and benefits of the SRA for Member States, the Commission and stakeholders groups;
- Recommend measures for optimising the use of existing research infrastructures and achieving cost-effective investments;
- Recommend measures for improving educational policies to attract the scientists, engineers and other skills that the sector needs;
- Develop and implement a communications strategy to promote awareness of the SRA (within the stakeholders community as well as to larger public audiences) and to disseminate information on stakeholders' research programmes for facilitating consensus on priorities.

Based on the listed activities each Member State defined its own national ACARE like activity in terms of technology platform or strategy. In order to map the national initiatives a survey was launched in 2009 by the ACARE Member States Group (MSG). The MSG represents the needs and objectives of the Member States and the EU Candidate Countries in the work of ACARE. Main outcome of the questionnaire was a comprehensive overview about most of the European countries. It was noted, based on the results of the report, that there are significant activities in Europe from research programme, national programmes, European research strategy implementation point of view. However there is a gap in measuring or comparing national strategies. In order to better understand the need for the survey and the place of it on European level a table has been included below.

Table 1. The Survey in the European context

	European level	Trans-national level
Strategy	ACARE SRA	ACARE MSG Survey
Programme	FP7	AirTN

3. Mapping Activity

After describing the needs for the survey, the data collection and structure of the questionnaire is described in this section.

The questionnaire was filled in mainly by Member States, as well as some EFTA countries, making up a total of 31 participants. As a reason of the number of countries involved, a huge amount of data has been collected covering areas such as personal data, national strategy data, current and future programmes. The other aspect of data collection was the identification of research infrastructure that supports the Aeronautics or Generic research programmes within individual countries.

The area of competences varied from flight physics through aero-structures to maintenance and safety (see appendix). It could be seen that different levels of capabilities are covered for example Propulsion (A3) and higher level Airports (A9). Therefore, to avoid misunderstanding or confusion, it was decided to use standard competencies or capacities based on ACARE taxonomy (ref).

The final result of the survey is a summary of competences that could be found in the Appendix (Matrix of Competences). The table includes the EU – 27 Member States and some candidate or potential candidate countries such as Croatia, Republic of Serbia or EFTA Countries. They are active participants of ACARE MSG meetings however they are not part of the European Union yet. It needs to be mentioned that not all countries provided information regarding competences, in their case special competences has been excluded.

4. Conclusion

In order to disseminate the results of the survey, a workshop of the ACARE MSG on Aeronautics Strategies in the EU Member States with the title "Developing the Aeronautics Research and Technology Potential in the EU Member States" was organised in Brussels on 22nd June 2010 (more information: www.airtn.eu). It represented a first step for some activities to map the national approach towards implementing the goals of the Aeronautics Strategic Research Agenda in developing the research and technology potential in Aeronautics at the midway stage of the Vision 2020. It became obvious that several Member States that joined the EU in 2004 and 2007 – also called the EU-12, need special support for enhancing their capabilities.

Appendix. Matrix of Competences (ACARE MSG Survey, 2010)

	A1 Flight Physics	A1.1 Aerodynamics	A2 Aero-structures	A2.1 Basic Materials	A2.2 Material Processing	A2.3 Structure	A3 Propulsion	A3.1 Environment Aspects	A4 Avionics	A5 On-board Systems & Equipment	A5.1 Mechanical Systems	A5.2 Electrical Systems	A5.3 Cabin Layout	A6 Flight Mechanics	A7 Integrated Design & Validation	A7.1 Collaborative Working	A7.2 Computing	A7.3 Simulation	A8 Air Traffic Management	A8.1 Communications	A9 Airports	A9.1 Airport Equipment	A10 Human Factors	A11 Innovative Concepts & Scenarios	A12 Others	A12.1 Maintenance	A12.2 Safety	A12.3 Image Treatment	A12.4 Other Technologies	Summary
MEMBER STATES																														
Austria			X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X		25
Belgium				X	X	X	X			X		X					X	X		X							X	X		11
Bulgaria		X				X		X				X		X		X		X					X			X	X			10
Cyprus								X			X						X					X				X	X			6
Czech Republic		X		X	X	X	X	X		X			X					X		X						X	X			12
Denmark																														0
Estonia				X			X	X	X										X	X			X	X		X	X			10
Finland	X	X	X			X							X	X				X				X	X			X				10
France	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		28
Germany	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		28
Greece	X	X	X	X	X	X	X	X	X					X	X	X	X	X	X	X	X			X	X	X	X	X	X	23
Hungary		X	X						X			X	X					X	X	X	X	X	X	X		X	X			14
Ireland			X							X		X	X		X		X	X	X	X			X			X				11
Italy	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	29
Latvia				X	X	X		X				X				X		X		X					X	X		X		11
Lithuania		X		X		X				X		X				X				X						X	X			9
Luxembourg																														0
Malta																														0
Netherlands	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		28
Poland	X		X				X		X	X				X	X				X		X		X	X	X					12
Portugal	X	X	X				X	X	X					X			X	X								X			X	11
Romania	X	X	X	X			X	X						X	X	X	X	X	X	X			X	X				X		16
Slovakia				X	X	X	X										X	X	X	X	X	X	X	X			X		X	14
Slovenia	X	X		X	X	X					X	X		X	X	X	X	X		X						X	X	X		16
Spain	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		28
Sweden		X		X	X	X		X	X		X	X				X			X				X	X						12
United Kingdom		X			X	X	X	X		X	X	X				X	X	X		X						X	X			14
Candidate and potential candidate countries																														
Croatia		X		X		X	X							X			X	X	X							X				9
Republic of Serbia		X		X	X	X				X	X	X		X	X			X	X		X			X		X	X			15
EFTA Countries																														
Switzerland	X	X	X	X	X	X	X					X	X	X	X		X	X		X		X				X	X			17
Summary	12	19	14	19	16	20	17	16	12	13	11	17	11	15	13	14	17	22	16	19	11	11	15	14	9	22	19	11	4	429

References

[1] A new beginning for European Aeronautics Research, http://www.acare4europe.com/html/introduction.asp.

[2] European Aeronautics: A Vision for 2020, January 2001, http://www.acare4europe.com/docs/vision%202020.pdf.

[3] Strategic Research Agenda, 1st and 2nd Edition, October 2004, http://www.acare4europe.com/html/documentation.asp.

About the Author

Javier Romero
Centro para el Desarollo Tecnológico Industrial (CDTI)
jjrr@cdti.es
www.cdti.es

Roland Gurály
National Innovation Office (NIH)/Slot Consulting Ltd.
rolandguraly@slotconsulting.hu
www.nih.gov.hu, www.slotconsulting.hu

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-447

GARTEUR – Long Term R&T Collaboration in Europe

Gunnar HULT and Björn JONSSON

Abstract. GARTEUR (Group of Aeronautical Research and Technology in EURope) is a multinational organisation that performs high quality, collaborative, pre-competitive aeronautical research. It is based on a government-to-government agreement (MoU) between seven European nations with major research and test capabilities in aeronautics. GARTEUR was formed in 1973 by the governments of France, Germany and the United Kingdom in the wake of the formation of Airbus. The Netherlands joined the group in 1977. Sweden joined GARTEUR in 1991, followed by Spain in 1996 and Italy in the year 2000. The GARTEUR focus is on research topics aimed at long term R&T because this is considered essential to assure sustained competitiveness of the European aerospace industries. A key asset of GARTEUR is its unique mechanism for cooperation, which has been used successfully for numerous collaboration projects over the past decades. It is the only framework in Europe for both civil and military aeronautics R&T.

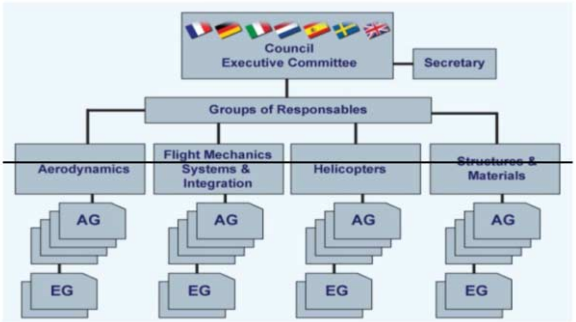
Keywords. GARTEUR, military and civil aeronautics R&T

1. Organisation

GARTEUR is organised around three main elements:

- A Council composed of representatives of each member country, who appoints the national delegations. Representatives are from all relevant Ministries and Research Establishments. The Council is assisted by an Executive Committee, composed of one member from each national delegation, and a GARTEUR Secretary;
- The Groups of Responsables (GoR), the scientific management bodies and think-tank of GARTEUR, are composed of representatives from government departments, national research establishments and industry. Currently, four GoRs manage GARTEUR research activities: Aerodynamics (AD); Flight Mechanics, Systems and Integration (FM); Helicopters (HC); Structures and Materials (SM);
- The Action Groups (AG), the technical expert bodies for project formulation and execution of the GARTEUR research work.

GARTEUR has no permanent secretariat or headquarters. The seven GARTEUR nations ensure alternately, and for a two year period, the Chairmanship of the Council and the Executive Committee. The chair country also provides the Secretariat for the same period.



2. Technical Activities

GoR AD (Aerodynamics) is active in experimental, theoretical, analytical and numerical fields of aerodynamics to encourage the developments and applications of methods, tools and procedures for both civil and defence applications. GoR AD focuses on:

- Applied and Fundamental Aerodynamics;
- Aerothermodynamics;
- Aeroacoustics;
- Aeroelasticity;
- Propulsion / Systems Aerodynamics Integration;
- Transition and Turbulence Modelling.

GoR FM (Flight Mechanics, Systems and Integration) is active in flight testing technologies and flight simulations, investigates air traffic control, sensor technology and systems and human factors. GoR FM focuses on:

- Air vehicle systems technology, incl. safety;
- Avionics;
- Certification;
- Performance;
- Stability & control.

GoR HC (Helicopters) is active to facilitate the advancement of civil and military rotorcraft technology, seeks to extend the flight envelope and performance, to increase safety and survivability, and to increase public acceptance. Technical disciplines include, but are not limited to:

- Aerodynamics;
- Aeroelastics including stability, structural dynamics and vibration;
- Flight mechanics & control and handling qualities;
- Vehicle design synthesis and optimization;
- Human factors;
- Internal and external acoustics and environmental impact;
- Simulation techniques and facilities for ground-based testing.

GoR SM (Structures and Materials) is active in initiating and organizing aeronautics-oriented research on:

- Structures;
- Structural dynamics;
- Materials.

Structures research is devoted to computational mechanics, loads & design methodology. Structural dynamics research involves vibrations, responses to shock and transient loads, aero-elasticity and acoustic response. Materials research is related to materials systems, including aspects of polymers, metals and composite systems.

3. Operational Principles

GARTEUR provides a very useful platform and network for scientists from research establishments, industry and academia to pool technology and knowledge in order to develop ideas and concepts in various aeronautical areas. As GARTEUR has no common funding the participants in GARTEUR projects have to bring their own funding (national or company internal). Since the establishment of EU aeronautics programmes in the 1990-ies there exists a permanent mutual influence between this EU environment and GARTEUR. Project ideas developed within GARTEUR may fit with the Call for proposal and then become an EU-FP project. After an EU-FP project, ideas to be further explored may result in a GARTEUR project.

The GARTEUR operating principals provide for participation by organisations from non-GARTEUR countries in GARTEUR technical activities, under a special procedure subject to approval by the Council. In this spirit the EU funded ERA-Net AirTN project, for which GARTEUR was the initiator, has been established. AirTN has successfully established and maintained an extensive network of European aeronautics stakeholder groups that includes ACARE and GARTEUR along with universities, and research institutes.

4. Conclusions

- GARTEUR has actively pursued European collaboration in aeronautics R&T for more than 30 years, covering both military and civil aeronautics R&T;
- Over the years more than 120 collaboration projects (Action Groups) have been performed, resulting in more than 170 technical reports. GARTEUR Open Technical Reports will be made available on the website;
- GARTEUR is a unique forum of aeronautical experts from Industry, Research Establishments and Academia;
- GARTEUR is the only framework in Europe for both civil and military Research & Technology for Aeronautics;
- A main GARTEUR asset is its unique mechanism for cooperation which provides a straightforward way to increase collaboration on dual use projects. Through the GARTEUR mechanism, both industrial and governmental partners with either civil or military funding can easily work together;
- GARTEUR takes a flexible and open approach towards participation in research projects of non-GARTEUR nations and organisations.

About the Authors

Gunnar Hult, GARTEUR Council Chair
Björn Jonsson, GARTEUR Executive Committee Chair
Defence Materiel Administration (FMV)
SE-115 88 Stockholm (Sweden)
gunnar.hult@fmv.se
bjorn.jonsson@fmv.se
GARTEUR Secretariat
Email: secretariat@garteur.org
Websites: www.garteur.org
www.fmv.se

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-451

EASN – The European Academia Association

Spiros PANTELAKIS

Abstract. The European Aeronautics Science Network – EASN – is the association of European academics active in aeronautics related research. Its primary aims are to promote, encourage, coordinate and focus joint efforts between Universities, Research Organisations, Industry and SMEs which are active in the field of aeronautics and aerospace.

Keywords. Academia, universities, research organisations

1. The European Aeronautics Science Network – Who We Are?

EASN is a large community of scientists from all over Europe with a common interest; Aeronautics and Aeronautics related activities. Its effective members consist of academics involved one way or another in Aeronautics related research, whereas associate EASN members are entities such as Universities and University labs as well as professionals from the Industry or Research Establishments active in Aeronautics research who cooperate with the academia. Through the 125 active registered members (individuals and institutions), EASN connects to more than 10,000 academic staff and professionals throughout Europe.

EASN initiated in 2002 as a European funded project, after realizing the need to tackle the fragmentation of the European Academia and the inefficient communication mechanisms between them. This led to significant overlaps in the Academic research and lack of a common University research strategy for the sector of aeronautics. The long-term goal by establishing EASN was to built up an open, unique European platform in order to structure, support and upgrade the research activities of the European Aeronautics Universities as well as to facilitate them to respond to their key role in realizing the European Research Area. Following 2 successive funded projects, the

EASN Association was founded in 2008 as an International non-profit Association governed by the Belgium Law for international not-for-profit associations and foundations.

The establishment of EASN and its recognition as the representative of the European Academia in Aeronautics research facilitates in expressing a collective University voice and shaping a common University policy. Its acceptance by the EC, the European Aeronautics Industry, the SMEs and the Research Establishments as their partner, gives the European Aeronautics Community the opportunity to introduce the Academia point of view to the EC officers and influence on active participation in different pan-European Aeronautics research activities. EASN has signed cooperation agreements with Associations representing European Aeronautics professionals, with respect to the exchange of information and research cooperation. The strategic partnerships of EASN as well as the wide spread of its members, allow EASN to disseminate Aeronautics related information to practically the whole Aeronautics community.

2. Our Aims

The primary aim of the Association is the advancement of the aeronautics sciences and technologies.

Further aims of the EASN Association are:

- The advancement of aeronautics technologies through innovative research and the support of European Universities, University Departments and Institutes as well as University research staff to perform aeronautics related research;
- The support of scientific and technological cooperation and human mobility;
- The support of and the participation to activities aiming to incubate new knowledge, technological innovation and breakthrough technologies;
- The dissemination of knowledge and technological innovation and the execution of dissemination work through its participation in national or international projects and research programs related to aerospace;
- The support, organization and participation to activities related to scientific knowledge and technology transfer;
- The execution of studies for the development of national and international policies on subjects related to the aims of the Association and the provision of consultancy services for the development of education, research and development policies and activities in aerospace;
- Collaboration with Universities, other academic Research Institutions, Research Establishments, the Industry, governmental and state authorities, the European Commission, etc. to support the aims of the Association;
- The assignment to Universities and other entities of contract work in the frame of its activities.

3. Why to Join EASN

Due to its multi-national nature, being a member of EASN opens the door to multilateral and bilateral international cooperation in Aeronautics. EASN provides the means

for locating partners for research activities of common interest, the preparation of joint projects as well as partnerships in student exchange programs. This is done either by the close cooperation established within the members of the EASN Interest Groups, as well as by the networking events prepared and carried out by the EASN such as informative and scientific workshops, meetings of Interest Groups members etc. The active participation in the EASN Interest Groups keeps the members in line with the state-of-the-art regarding research activities in the respective areas and in contact with the platforms of the most promising and effective international cooperation; in consequence where the highest chances for European research projects granted by European Commission are.

Furthermore, EASN membership allows for access to information provided through the website such as conference proceedings, participation to expressions of interest campaigns, working groups and requests for input towards the EC and ACARE. Finally, enrolment in the EASN database also allows for the EASN members to be visible to the national and international communities in Academia, Industry and major Research Organisations.

4. Who Can Join EASN

1. Effective members (with voting rights);
    - Individuals from European Academia or other University-similar organizations, who are active in Aeronautics related research.
2. Associate members;
    - Individuals from Research establishments, SMEs and Industries, who are active in aeronautical research activities and cooperate with the academia;
    - Entities such as Universities, University departments, REs, SMEs, Industries, other associations, professional organisations or governmental agencies (e.g. EC) subscribing to the objectives of the Association;
    - Each entity will be represented by a single person.
3. Honorary members;
    - The title of Honorary Member or Honorary President may be granted by the General Assembly to persons who have rendered outstanding services to the Association;
    - Honorary President takes juris et de jure part in the General Assembly and Board meetings with a consultative vote.

5. How to Join EASN

Registration in EASN and enrolment in the EASN database can be made easily on-line from the EASN website. Information on EASN and its activities, as well as on how to join the EASN Association can be found under www.easn.net.

About the Author

Spiros Pantelakis
EASN Chairman
Laboratory of Technology and Strength of Materials
University of Patras – Panepistimioupolis Rio
26500 Patras (Greece)
Tel.:+30 2610 969498
pantelak@mech.upatras.gr
http://ltsm.mead.upatras.gr/lab/lang_en/
www.mech.upatras.gr

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-455

The French Competitiveness Clusters in a European Context: Getting Together Research LABs, Large Industry and SMEs

Thilo SCHÖNFELD and Katja SCHÖNTAG

Abstract. European competitiveness is essentially driven by dynamic industry and technology-based clusters. In fact, globalisation on the one hand has strengthened the role of regional clusters on the other hand. As a result, along with increasing market globalisation, increasing resources will flow to the more attractive regions, reinforcing the role of clusters and driving regional specialisation. These clusters enable companies, research organisations and regions to join forces for their mutual development and innovation. In a steady process, European clusters are seeking to improve and strengthen their performance and innovativeness. The present paper presents the regional cluster policy currently applied throughout Europe (and worldwide) to the aerospace sector. Although this paper mainly focuses on the activities of the French competitiveness cluster "Aerospace Valley", perspectives on the future evolution in the context of European and international collaboration are provided.

Keywords. Cluster, aerospace valley, EACP (European aerospace cluster partnership)

1. Introduction

In application of Michael Porter's definition of clusters as "geographically proximate groups of interconnected companies and associated institutions in a particular field, linked by commonalities and complementarities" [1], the European Council held in Lisbon in 2000 set the ambitious goal to make Europe "the world's most competitive and dynamic knowledge-based economy".

Indeed, with the globalization of operations, significant socio-economic developments, and new market entrants, the European aerospace industry faces enormous challenges. During the past decade, the regions' answer to these developments has been the bundling of resources and competences by clustering. Policy makers have been honoring this approach by including clusters as a priority action to strengthen European innovation.

Europe's aerospace industry is very research-intensive with overall R&D expenditure above average for manufacturing industries. International competition is strong; European competences require staying one step ahead in terms of technology level and processes in order to stay competitive in the world market.

Figure 1. Map of French Competitiveness Clusters (Copyright: Aerospace Valley).

2. The French Regional Cluster Policy

Based on a number of economic studies and analyses conducted mainly in Europe and Asia, the French government has established a national policy of regional competitiveness clusters ("pôles de compétitivité") to stimulate innovation and cooperation between industry, research and education [4]. These competitiveness clusters are a forum for the creation of collective projects between companies, research centres, and academic institutions. R&D projects are the clusters' core activities and constitute the main factor of their competitiveness. Non-R&D projects (training, property investments, infra-structures, economic developments, promoting local areas, international expansion, etc.) also make key contributions to the competitiveness of the cluster's companies and the regional economic development.

Following a first competitive "top-down" call for projects published in 2004, in July 2005 the cluster "Aerospace Valley" devoted to aeronautics, space and embedded systems, received approval along with 66 other clusters covering basically all of the industrial sectors and economical tissues in France (Fig. 1). As one of six clusters from different sectors, Aerospace Valley was designated as a "global player" cluster.

3. Aerospace Valley

Aerospace Valley was created in 2005 and today is the leading innovative competitiveness cluster in France dedicated to the sectors of aeronautics, space, and embedded systems. Gathering the two regions Midi-Pyrénées and Aquitaine in the Southwest of France, Aerospace Valley now has more than 560 members including 80 primes and over 260 SMEs as well as a number of major aerospace research establishments and engineering schools. Overall, members of Aerospace Valley represent one third of the French aerospace workforce with around 115,000 employments in 1,300 industrial establishments. A total of 12,500 researchers and scientists are active on the Aerospace Valley territory representing 45% of the total French national R&D potential in the related sectors.

The two complementary regions of Midi-Pyrénées and Aquitaine, by combining their strengths, constitute one of the leading European centres for space and aeronautics activities and in the field of on-board systems. By harnessing all sources of energy – major groups, small and medium-sized enterprises, public and private research centres, universities, graduate schools of aerospace engineering and regional authorities, the cluster sets ambitious objectives for the upcoming two decades. Aerospace Valley actually has to be considered as a huge innovation think tank based on the "triple helix" concept and structured in the triangle of industry, research, and training rather than a primarily business-oriented "cluster" following the Anglo-Saxon definition. By March 2011, 410 collaborative R&D projects had received Aerospace Valley approval, 220 of them are currently running. They are mainly financed through various private and public funding mechanisms.

French cluster policy and support is characterized by a strong focus on a limited number of regions. Beside Aerospace Valley, there are two additional clusters dedicated to the aerospace sector that were approved in 2007: ASTech in Ile de France and PEGASE in the Provence-Alpes Côte d'Azur region. These two clusters have set up strong links under the guidance of Aerospace Valley in order to guarantee the most efficient use of private and public resources on a national level. As an example, periodic reviews and evaluations of the R&D projects are conducted, best practices are shared and international initiatives are coordinated. International cooperation is part of this economic development plan. At present, Aerospace Valley has signed formal cooperation agreements with five international clusters while several informal contacts have been established with aerospace clusters, particularly in China and Brazil. Additionally, it is a member of the European Aerospace Cluster Partnership (EACP), cf. below.

4. The European Context

4.1. European Cluster Approach

The European Commission has recognized the value of clusters and their contribution to the European goals of jobs and growth. At a European Conference on Innovation and Clusters held in Stockholm in January 2008, the European Cluster Memorandum [6] was presented. It had previously been prepared in 2007 by a High Level Advisory Group of experts on clusters established by the European Commission. The Memorandum seeks a strong commitment from public stakeholders at all levels to further support cluster development in their respective territories. It recognizes that clusters are "important drivers of innovation and contribute to the competitiveness and sustainable development of European industry and services". It postulates that "strong clusters emerge and flourish best in open markets where 'co-opetiton' (i.e. a blend of cooperation and competition) exists within and between clusters" [6].

Since then, the importance of supporting regional research-driven clusters in Europe has been recognized in various European policy and action plans, including the Broad-based Innovation Strategy and the latest Europe 2020 Strategy with its Lead Initiative for industry policy.

Figure 2. EACP Logo (Copyright: EACP).

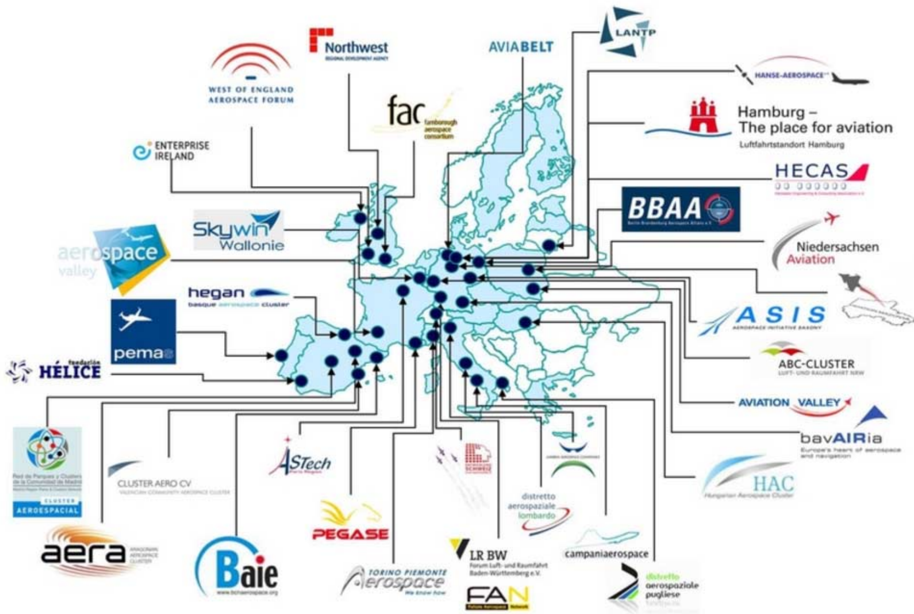


Figure 3. EACP Member Map (Copyright: EACP and its members (for logos).

4.2. The European EACP Network

The European Aerospace Cluster Partnership (Fig. 2) was founded in 2009 as a network between European research–oriented regional clusters mainly in the field of aeronautics [7].

The main objective of this network is to strengthen Europe's aerospace position in the worldwide markets through its clusters and regions. With its currently 38 members from 13 European countries (Fig. 3), this network has become a platform for exchange of best practices and information on cluster management, particularly in the fields of internationalization, skills & innovation, and cluster funding [8]. The cooperation is fostered through joint projects, such as the CARE project (Clean Aerospace Regions) that was successfully submitted under FP7 by a consortium of 10 European aerospace clusters.

Such more or less informal networks offer an overall framework for investigating new approaches in the promotion of innovation and R&D activities and for comparing novel tools for cluster management. The clusters of the EACP consortium indeed are very heterogeneous in terms of size, governance, degree of industry implication, im-

plementation of innovation strategies, RDT policies, etc. All three of the French competitiveness clusters in aerospace are active EACP members. They are generally considered as situated in an intermediate position concerning governmental involvement (vs. purely industry-driven clusters) with a strong emphasis on technology. Presently, a second focus is on R&D activities and the elaboration of collaborative research projects.

With the current French cluster policy and the developments on a European level concerning cluster support, it is to be expected that clusters will, over the next decades, be strong determinants of the European industry landscape. Policy makers as well as cluster managers are still learning how to optimize the strategic and operative support for clusters, but with the lessons learned so far and increasingly efficient structures in place, clustering is a powerful tool for Europe's industry and its competitive advantage.

References

[1] Michael E. Porter, "Clusters and Competition", in: On Competition, Harvard Business School Press, Cambridge, 1998.

[2] Christian Ketels, "Structural Change in Europe 3 – Innovative City and Business Regions", Harvard Business School, 2004.

[3] Christian Ketels, Göran Lindqvist and Örjan Sölvell, "Clusters and Cluster Initiatives", Center for Strategy and Competitiveness, Stockholm School of Economics , June 2008.

[4] DATAR, "La France, puissance industrielle: une nouvelle politique industrielle par les territoires", Paris, La documentation française, 2004.

[5] Contact: Center for Strategy and Competitiveness, Stockholm School of Economics, P.O. Box 6501SE-11383 Stockholm, email: info@clusterobservatory.eu.

[6] Pierre Laffitte et al. (high-level advisory group), The European Cluster Memorandum, Stockholm, January 2008.

[7] Thilo Schönfeld, "Clustering the Regional Aeronautical Clusters", European Commission – DG RTD Transport, Member States Workshop, Brussels, May 2007.

[8] Rüdiger Hintze-Schomburg, Katja Schöntag and Walter Birkhan, "Stronger Together", Public Service Review: European Union, Issue 18, September 2009, pp. 456–457.

About the Authors

Thilo Schönfeld
Deputy Director International Affairs
Aerospace Valley
23, avenue Edouard Belin
F-31400 Toulouse (France)
Tel.:+33 (0)5 61 14 80 30
schoenfeld@aerospace-valley.com
www.aerospace-valley.com

Katja Schöntag
European Cooperation, EACP
Aviation Cluster Hamburg Metropolitan Region
Alter Steinweg
D-20459 Hamburg (Germany)
Tel.:+49(0)40 42841 3398
katja.schoentag@bwvi.hamburg.de

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-460

Trends in Educational Activities and Tools for Aeronautics – The Example of the von Karman Institute

Herman DECONINCK

Abstract. The recruitment of highly skilled engineering labour force will be a severe bottleneck for Aeronautical Industry, in order to meet the challenges resulting from the greening of air transportation (ACARE 2020 Vision and the Flightpath 2050). The author of this paper presents an approach drawn from the Belgian von Karman Institute experience, and which could contribute to overcome the obstacles.

Keywords. Recruitment, bologna process, VKI, higher education, industrial needs, diploma, research masters, PhD, lifelong learning programmes

1. Introduction

To cope with the challenges resulting from the greening of transportation, two different trends are crucial: the first is the creation of a truly international market for higher education in Europe as targeted with the Bologna Declaration, allowing European wide recruitment of the best forces. Second, an increased focus on training for innovative research will be needed. It is advocated that this can only be achieved by an increased focus on Research Masters specializations next to the traditional PhD programmes. These educations further have to be strengthened with an increased emphasis on lifelong learning programmes for professionals and exchange programmes for top experts between academia and industry. Together, these three types of programmes form the triad of top level higher education in Aeronautics. They benefit from strong synergies when organised on the same campus, as illustrated by the example of the von Karman Institute for Fluid Dynamics.

2. The Bologna Process

The Bologna Declaration of the European Ministers of Education, convened in Bologna on the 19th of June, 1999 [1], marks a turning point in the development of European higher education. Twenty-nine countries pledged to reform their different higher education systems towards convergence, which has come to be known as the Bologna process. In the meantime 47 countries have joined. The declaration is not just a political statement, but a binding action programme based on a clearly defined common goal, a deadline and a set of specified objectives:

- A clearly defined common goal: to create, by 2010, a European space for higher education in order to enhance the employability and mobility of citizens and to increase the international competitiveness of European higher education (compared to other continents);
- A set of specified objectives: (1) the adoption of a common framework of readable and comparable degrees; (2) the introduction of undergraduate (first cycle, Bachelors, BS) and graduate (second cycle, Masters, MS) levels in all countries, with first cycle degrees (BS) no shorter than 3 years and relevant to the labor market; (3) the introduction of a common European Credit Transfer and Accumulation System (ECTS) for course credits, also covering lifelong learning activities (1 ECTS corresponds to a total student load of ± 30 hours); (4) the establishment of a European dimension in quality assurance, with comparable criteria and methods; (5) the elimination of remaining obstacles to the free mobility of students (as well as trainees and graduates) and teachers (as well as researchers and higher education administrators).

Next to the need to "achieve greater compatibility and comparability in the systems of higher education" (mainly an intra-European issue), the Declaration wants "in particular" to increase "the international competitiveness of the European system of higher education".

New objectives have been added (since 2003, 2005), which are (1) the inclusion of the third cycle in the process: PhD programmes and Master after Master and (2) lifelong learning as a recognized mission of higher education institutions, with the aim to stimulate also the cooperation between industry and educational institutes in the field of lifelong learning.

In conclusion, one can state that the Bologna process has created a European-wide market for higher education.

3. Industrial Needs and Requirements in Aeronautics

Considering the demand from the aeronautical industry for skilled employees in engineering sciences, an increased focus on innovation and research can be recognized over the recent years. This focus results from the extreme challenges to be faced in the coming 30 years, as described in the ACARE vision 2020 [2], recently (2011) updated to "Flightpath 2050" [3].

Increased environmental constraints, the so called "greening" of aeronautics, requires unprecedented improvements in fuel efficiency of aircraft (reduction of CO_2), reduction of noise emission and reduction of NO_X. These requirements may be so drastic that evolutionary changes might not be sufficient. Instead, it could be necessary to completely rethink air transportation in the next 30 years, with innovative aircraft configurations (blended wing-body, flying wing, …), innovative engines (contra-rotating open rotor, …) and sophisticated flow control (laminar wing, synthetic jets, Dielectric Barrier Discharge (DBD) or plasma control, MEMS, morphing etc.).

Such changes will be deeply rooted in fundamental science and understanding of all the detailed physics involved such as turbulence, transition and interdisciplinary coupling effects (e.g. aeroacoustics, aeroelasticity, heat transfer, chemistry).

At the same time short production cycles will require new design methodologies, involving interdisciplinary collaboration at international level from different locations

(concurrent engineering, collaborative tools) and Multidisciplinary Design and Optimization (MDO) including off-design. This should ultimately lead to the “numerical Flight-Testing of the virtual aircraft” (Dr. A. Abbas, Airbus, at a recent workshop of the EU FP7 GRAIN project).

Such advances will require fast and high fidelity experimental validation of new concepts: improved accuracy and sophistication of experimental approaches (non-intrusive techniques, cryogenic wind tunnel (ETW)) as well as faster processing by field measurements (PSP, PIV …).

4. Consequences for Higher Education

Evidently the role of research and higher education will be crucial to meet the challenge of developing a highly skilled labor force. The Bologna process is therefore certainly a step in the right direction, but it is by far not sufficient. The top level higher education in Aeronautics (and other fields of engineering) has to focus more on innovative research by (1) training engineers for doing innovative research; (2) providing thereby top level facilities and instruments; (3) bringing students into contact with the research programmes funded by industry, governments or supranational organisations (EU, ESA); (4) having permanent contact with research and design departments in industry; (5) providing an international recruitment and working environment (Erasmus, Marie Curie, MaM programmes …); and (6) encouraging personal contact of students with experts (e.g. by organising host programmes for visiting experts, short courses …).

At the political and institutional level, this requires increased focus on programmes beyond the first and second cycle targeted in the initial Bologna Process.

- There is an important need for a specialization in research beyond the primary Master, but less focused than the PhD studies. This observation explains the increased importance of third cycle programmes such as Research Master programmes in aeronautics (at the level Master after Master) next to traditional PhD programmes;
- Engineers in industry and government research centers need to upgrade continuously their knowledge by lifelong learning (e.g. following short training courses, with highly specialized, top lecturers). This creates an important need for high level lifelong learning programmes on an institutional basis;
- Exchange programmes between industry and academia become crucial: top level industrial experts should be allowed to take a temporary leave as visiting professors in academic institutions. Similarly, academic staff should gather real life industrial experience by working for short periods in industry and/or by carrying out research under contract and in close collaboration with industry.

These observations bring us to the triad of educational programmes at the top level (Fig. 1): (1) the Research Master at Master after Master level which aims to provide highly skilled engineers for the industry and research institutes, or for continued PhD studies, (2) the PhD studies and (3) the lifelong learning programmes for professionals from industry, research centers and academia (researchers or PhD candidates).

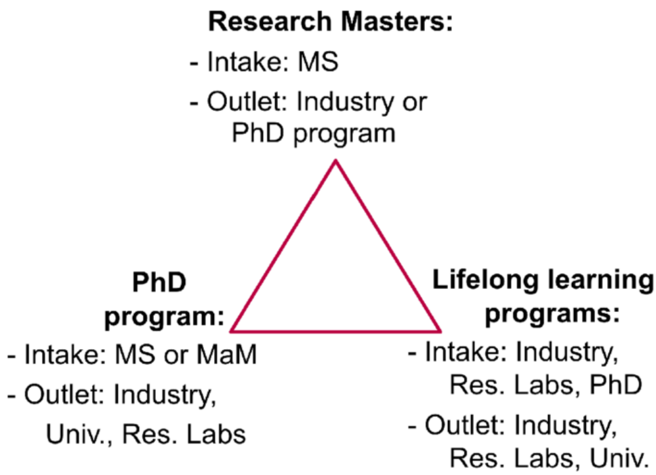


Figure 1. The Triad of top level higher education programmes for innovative research. Strong synergies are present when organised on the same campus.

When organised on the same campus, these 3 types of education benefit from strong synergies: The Research Master students are integrated in the funded research programmes carried out by PhD candidates; the PhD candidates profit from the advanced short courses and the contact with renowned experts (with industrial experience) invited to teach these courses; the short courses can even be organised with the aim to attract the complementary expertise for PhD research when such expertise is missing at the institutional level.

5. The Example of the von Karman Institute for Fluid Dynamics

In many respects, the VKI can be viewed as a forerunner in this multifaceted vision of European higher education in aeronautics: starting 55 years ago, the VKI was a trend setter in the creation of a third cycle programme and a lifelong learning programme at European and even trans-Atlantic (NATO inspired) level:

- The third cycle programme "Diploma Course" was a programme of 1 academic year of specialized training for aeronautical engineers, started in 1956 by Theodore von Karman. It has delivered over 1500 graduates since 1956, from over 15 different nationalities;
- The lifelong learning programme "VKI Lecture Series" is a programme of 1 week specialized short courses for professionals organised since more than 40 years. It offers 10–12 courses each year, attracting over 300 participants per year from more than 15 countries.

6. From Diploma Course to Research Masters

Starting in October 2010, the VKI Diploma Course programme has been fully converted to the Bologna process as a third cycle programme at the level of Master after

Master with a duration of one year. It has been accredited by the Dutch-Belgian (Flemish) accreditation organisation NVAO which ensures a quality assurance at European level, and it follows the ECTS-compatible credit system. Further it has preserved all the assets and experience of 50 years of the VKI Diploma Course: strong integration with research (PhD research, EU or ESA-funded research), international recruitment (more than 12 nationalities represented) and synergies with the Lecture Series programme. Its key ingredients follow the line of the tradition of the Diploma Course:

1. Course work: 30 ECTS with 2 orientations in aeronautics (Aeronautics/Space and Turbomachinery/Propulsion) and 1 orientation in environmental and industrial flows (bio, wind, environment, climate). The course work offers experimental and numerical options, with a strong interdisciplinary aspect (experimentalists are also trained in numerical simulation and vice versa). The methodology is a hands-on approach, combining theory, homework, and laboratory experience, with a strong link to industrial practice and needs. Training in research includes also methodology of research, bibliographic search, presentation and reporting and project management;
2. Research project (Master thesis): 30 ECTS with a strong coupling to existing funded research projects giving access to top facilities and resources and leading to "real life" research including also the management of the project: scheduling and managing of resources and technical staff. There is a close follow-up with three periods of reporting in front of an evaluation team as well as training in public presentation.

7. PhD and Lecture Series Programme in Fluid Dynamics

The von Karman Institute also has an extensive PhD programme with a community of over 60 PhD's in residence, all related to fluid dynamics, both experimental and numerical. The PhD thesis is defended at a university either in Belgium or abroad.

Finally, the VKI Lecture series programme is a lifelong learning programme for professionals from Industry, Research Institutes and Academia (advanced courses for PhD candidates), created more than 40 years ago. The duration of the courses is between 3 and 5 days. The teachers are experts invited from all over the world. The extensive course notes prepared for each Lecture Series have become valuable reference material in the field.

Complemented with an extensive short training programme at undergraduate level, the Research Master, the Lecture Series and the PhD programme offer a unique and truly international environment for education and research in Aeronautics and Fluid Dynamics in general.

8. Conclusion

The top segment of higher education should focus on: (1) training for innovative research with an important role for Research Master studies at Master after Master level, next to PhD studies; (2) lifelong learning programmes for professionals, in close contact with the industry and research centers. The von Karman Institute has developed more than 50 years of experience in this area.

Key ingredients are (1) to link the education with ongoing research projects (EU, ESA, national, regional); (2) to link the education with industrial needs and applications; (3) to have an international dimension both in the teaching and student body (following Bologna); (4) to teach collaboration in international networks and teams, stimulating proficiency of languages; (5) to stimulate lifelong learning programmes for professionals (short courses); (6) to stimulate/create exchange-visiting programmes with experts from industry and research centers, also with partner universities and (7) to exploit the strong synergies between different third cycle programmes at one site: the triad of PhD – MaM – Short Course (Lecture Series).

References

[1] The Bologna Declaration on the European space for higher education: an explanation, prepared by the Confederation of EU Rectors' Conferences and the Association of European Universities (CRE), http://ec.europa.eu/education/policies/educ/bologna/bologna.pdf.
[2] European Aeronautics: a vision for 2020, Meeting society's needs and winning global leadership; report of the group of personalities, January 2001, http://www.acare4europe.org/docs/Vision 2020.pdf.
[3] Flightpath 2050: Europe's Vision for Aviation, Report of the High Level Group on Aviation Research, 2011, http://ec.europa.eu/transport/air/doc/flightpath2050.pdf.

About the Author

Herman Deconinck
Dean of Faculty, von Karman Institute for Fluid Dynamics
Waterloosesteenweg 72
B- 1640 Sint-Genesius-Rode (Belgium)
Tel.:+32 2 3599618
deconinck@vki.ac.be

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-466

Russian Aeronautics Research Programmes

Liudmila ROSTOVTSEVA

Abstract. Ministry of Industry and Trade of Russian Federation supports research in the field of civil aviation through the federal target programme “Development of Russian Civil Aviation for 2002-2010 and through 2015”. Attaching great importance to international cooperation, the Russian organisations are actively involved in the EU Framework Programmes. In the frame of the third competition FP7 in the field of aeronautics and air transport, the coordinated competition “EU-Russian Aeronautics research” has been launched. As a result of the competition, three projects are currently underway. This paper describes approaches to development of Russian aviation industry with the help of aeronautics research programmes.

Keywords. Russian aviation industry, EU-Russian aeronautics research

1. The Russian Aviation Industry

The development of Russian aviation industry is being implemented in conformity to the Strategy that was approved in 2006. The task of this strategy is to provide the fostering a new organisational branch structure. The efficient fulfilment of policies:

- Creates the aeronautic engineering and promotes it into potential markets;
- Involves the resources needed and regulates these resources based on state and private property partnership.

Nowadays we can state that the key integrated industry structures formation is completed. They are as follows:

- The United Aircraft Corporation JSC in area of aircraft engineering;
- The Russian Helicopters in helicopter engineering;
- The United Engine Corporation in propulsion engineering;
- Also the formation of the integrated structures in aircraft-borne instruments making industry and in airplane units engineering will be soon completed.

2. A High Scientific and Technical Potential

The activities of the major Russian State Research Centers that are TsAGI, CIAM, VIAM, GosNIIAS and others are well known to the aeronautics community all over the world. They are characterized by the high scientific and technical potential, the scientific schools of the world level and the unique research and test basis. Their activity focuses on creating the scientific and technological groundwork, the applied technologies and scientific and technological solutions.

3. The Nearest Challenges

The nearest industry challenges in civil sector are:

- Promoting the SSJ-100, Tu 204CM, An-148 aircrafts into international and nation markets correspondently;
- Creation of the SSJ-NG aircraft, the medium haul MC-21 aircraft, a new generation engine intended for “breakthrough” products;
- Implementation of projects in helicopter engineering, including the completion in creation of Mi 38 and Ka-62 helicopters.

Based on the results of the previous year it is to be point out the beginning of the series production of SaM-146 engines for Sukhoi Superjet-100 aircraft. The engine is certified in conformity to European Airworthy Rules and meets the Interstate Aviation Committee (IAC) requirements. The aircraft as it is, is awarded the IAC type certificate. This year we expect to be awarded a European certificate to this aircraft.

A gas generator of principally new PD-14 engines family was created. It is suited expressly for MC-21 aircraft project, the aircraft professionals are actively contributing into.

4. The Key Priority-Driven Requirements to the Air Transport System

Nowadays when our national researches and developments are targeted to the implementation of innovative evolution of the state, the key priority-driven requirements to the air transport system are to be:

- Flight safety and regularity;
- Reducing the environmental impact;
- Energetics and resource-saving;
- Air transport affordability.

5. Financing

The Federal Target Programmes (FTPs) constitute a principle R&D financing instrument. As far as it concerns the civil aircraft engineering the Ministry of Industry and Trade of the Russian Federation (MIT) is customer-coordinator of FTP under the title “The development of the Russian civil aviation for 2002–2010 period and for period up to 2015”.

Accordingly to the legislation in force, all the projects that are eligible to be founded within the above mentioned FTPs are selected based on research topic proposals calls which of the strategic importance and the industrial potential are taken into consideration. The key topics in Call areas are selected by the Expert Council.

The terms of proposals examination and their evaluation within Calls are regulated by legislation.

Various evaluation criteria may be used in dependence of the particularly individual FTP but the principle ones are:

- Proposed activity duration;
- Finances required;
- Applicants professional ranging in proposed research area;
- Quality indices of the project submitted.

The same rules are valid for the joint international programs of MIT of Russia, including during the coordinated Calls.

The financing within the above mentioned FTP is provided for research in aerodynamics and strength, aircraft propulsions, avionics, aviation materials and technologies, and is aimed at the primary structure weight saving and the aircraft life-time increasing, the engine noise and emissions level reducing as well as reducing the sonic boom impact on humans and environment, the enhancement of air vehicles control and navigation accuracy, as well as the human factor consideration in control system.

The flight test technique development, the perspective norms and the aviation engineering requirements establishment, the Russian and international standards, norms and technical documentation and simulators technology harmonization, are also planned to be enhanced.

6. The Participation in EU – FP

While mentioning the international cooperation in aeronautics research, it is to be marked that the Russian aviation research centers participate actively in EU FP Calls and at that this participation percentage success is rather high.

To the end of creating the favourable conditions for further expansion of EU and Russia cooperation in civil aviation research and enhancing the competitiveness of this strategically important industry sector, the Directorate Transport EC Research Directorate General and the Aviation Department of Russian MIT established jointly an Aeronautics Research Working Group.

The Working Group prepared and kicked-off successfully in frame of the 3-rd FP7 Aeronautics and Air Transport call the Coordinated EC–Russia aviation research call.

Now it is possible to be stated that the Coordinated call has been established. The main tasks we set are achieved: the call is coordinated in timetable, budget amount, terms of implementation in topics and in executors.

In conformity to procedures and terms coordinated within the Working Group, three projects were selected and are financed by EC and the MIT of Russia (SVETLANA, ORINOCO, ALASCA).

The call was performed in two stages. At the first (European) stage 5 topics of 10 were recommended to be considered at the next (Russian) stage where 3 proposals were selected and recommended to be granted as the best ones within both the European and Russian call stages.

We have obtained a valuable experience that can be used within the future joint calls.

Currently the industry faces to new challenges in development and implementation of novel mechanisms for modernization and innovative development, updating the industry long termed aims in behalf of socio-economic development of Russia.

Within the processes being implemented the matter of enhancing the research centers activities, including the role they play in industry and state modernization, is under scrutiny study now.

7. Towards New Initiatives with a View to Concentrating Research Organisation

The matter of concentrating the research organizations resources through creating an Associated Aviation Research Center based on FSUE TsAGI n.a. N.E. Zhukovsky is under consideration.

Under coordination by the Russian Ministry of Industry and Trade the innovative programs conceptions are already developed by corporations and the Technology Platforms started to be formed that will become an efficacious instrument for state scientific and technological strategy implementation. The Technology Platform is called “Aeronautical mobility” in aviation industry.

8. International Cooperation

The international cooperation both in the research area and in the area of development and production of aircraft engineering will continue developing. In such a situation the intellectual property rights on the jointly generated products are getting of greater vitality as well as the financing the joint activities and the mutual admission of norms when developing and creating new engineering.

We are of opinion that the relevant Working Groups constitute the efficient platform where the principles of our future cooperation may be stated and negotiated.

About the Author

Liudmila Rostovtseva
Deputy Director of Aviation Industry Department
Ministry of Industry and Trade Russian Federation
www.minprom.gov.ru

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-063-5-470

Latin America – EU: Experience and Potential for Cooperation in Aeronautics and Air Transport Research

João Pedro TABORDA and Jean-Paul DOMERGUE

Abstract. The CoopAir – Latin America (CoopAir-LA) aimed to address the need for a more systemic assessment in identifying the research fields with higher potential for cooperation in Research and Technology for Aerospace (Aerospace R&T) between Europe and Latin America.

Keywords. Latin America, CoopAir-LA

1. Introduction

Recent years have witnessed an increase in cooperation between Latin America and the European Union in the area of aerospace R&T. Such dynamics has provided the conditions for the development of this Coordinated Support Action, CoopAir-LA, focused on defining a roadmap that will allow this cooperation to be taken to a next level.

CoopAir-LA has run for 18 months, with its final workshop in Brussels on September 2010. The consortium included companies and research organisations from the EU (Spain, Portugal, France and Poland), and counterparts in Latin American countries with experience in aerospace R&T: Brazil, Mexico and Argentina (although not represented in the consortium, attention was also paid to Chile).

The project focused on four major goals: i) to build a database with the main organisations working in aerospace R&T in Latin America, and respective areas of expertise [1]; ii) to analyze factors that impacting cooperation between the two regions in this area; iii) to present policy recommendations that will contribute to bring the current cooperation to a next level; iv) identify the research areas with a stronger potential for cooperation in aerospace R&T between the EU and Latin America.

As the outcomes of the project, CoopAir-LA has available a database with Latin American organisations and their areas of expertise. Such database was developed with the support of three workshops in Latin America (Brazil, Argentina, and Mexico[1]), during which participants became more familiar with the opportunities provided by the Framework Programme.

These events also allowed for the project to gather information on where Latin American organisations identify issues and opportunities to enhance cooperation with their European counterparts. Dissemination of information in Latin America about the EU Framework and facilitation actions to establish regular links with those counterparts were identified as major factors, while analysis on the current projects involving Latin American partners shows no issues in what concerns the quality of their work, making them case studies to be disseminated both in Europe as in Latin America as successful examples of cooperation between the two regions in this specific industry.

Figure 1. Database with Latin American organisations.

As conclusions, the project prepared its recommendations on the policy actions that, once implemented on both sides with the continuous involvement of academia, research centres and industry, may contribute to develop further cooperation between the EU and Latin America in the research fields identified of higher potential. These include biofuels, composite materials, metallic structures, design of aerostructures, aerodynamics, flight physics (including simulation), and noise and vibration.

Beyond discussed in specific meetings, those recommendations were presented to representatives of the European Commission and also to officials from the Latin American countries represented in project.

2. Aerospace-Related Competencies in Latin America

Latin American countries have different levels of experience within the aerospace industry, with Brazil, Argentina, Mexico and Chile having higher visibility based on the national strategies they have been pursuing in recent years.

Due to the development of Embraer in the recent decades, Brazil has established itself among the restricted group of nations which host today a final integrator for commercial aviation. The industrial policy that, among other results, lead to the creation of Embraer in 1969 had its origins during the 40s with the creation of the Instituto Tecnológico de Aeronáutica in the city of S. José dos Campos in the state of S. Paulo.

The creation of Embraer and its strong development in the last two decades established a strong dynamics in Brazil, not only in the state of S. Paulo but also in other areas of the country like the state of Santa Catarina with the local Federal University involved in several projects in the field of noise and vibration.

Neighbouring Brazil, Argentina has also a long tradition in the aerospace sector, having established several partnerships with Brazil, including the joint development of

a regional aircraft in the early nineties, the CBA-123 project. Additional activities are now expected from the participation of the Argentinean industry in the development of the Embraer KC-390 military cargo aircraft under a program coordinated by the Brazilian Air Force.

Beyond this type of activities involving design and manufacturing of structures, Argentina hosts distinctive competencies in avionics and systems, particularly in the region of the capital Buenos Aires.

Also emerging from the region as a Global player is Mexico, with its policies highly focused on the attraction Foreign Direct Investment. The state of Querétaro has been particular dynamic in such regard, currently hosting 14 large firms, most of them with industrial operations of increasing complexity and technological content.

Despite the absence of a partner in the project, the CoopAir-LA consortium decided to include Chile as the fourth case to be analysed under the project, having achieved important results in the last two decades based on the development of Empresa Nacional de Aeronáutica, ENAER, and its regular involvement in Embraer and CASA's commercial and military programmes[2]. This has allowed the country to consolidate local competencies in the area of metal structures, including the assembly of fuselage sections.

3. Experience of Latin American Partners in Framework Programme Projects

Framework Programmes 6 and 7 have witnessed an increasing participation of Latin American partners in EU-funded projects for aerospace, particularly by Argentinean and Brazilian partners. Under Framework Programme 6 (FP6) it was possible to identify four projects in four different fields, while three at least are to be added from Framework Programme 7 (FP7).

Under FP6, and based on its competencies related with numerical methods and tools, the Instituto de Desarrollo Tecnológico para la industria Química at the Universidad Nacional del Litoral was part of two projects: RAPOLAC (Rapid Production of Large Aerospace Components, [2]) and SYNCOMETS (Synthesis of aeronautical compliant mechanical systems).

The other two projects in FP6 with the participation of Latin American partners involved two Brazilian organisations. X3-Noise was coordinated by engine manufacturer Snecma, with the participation of the Federal University of Santa Catarina who brought into the consortium its distinctive competencies in the area of noise and vibration.

FP6 also saw the first participation of Brazilian OEM Embraer under the DIANA project, dedicated to research in the area of avionics and coordinated by a Portuguese SME, Skysoft.

Beyond CoopAir-LA Coordinated Support Action, Embraer is also involved in the ADVITAC project, coordinated by French company Daher, and focused on research that may lead in the future to the development of a full composite tail cone.

Coordinated by the Portuguese University, Instituto Superior Técnico, the NOVEMOR project is another FP7 project with the participation of Embraer, in the area of aerospace structures. Outside FP7's aerospace calls, Embraer is also part of KARYON consortium in the field of sensors network. The project was approved under the scope of one the European Commission's call on Information, Communications and Technology.

Figure 2. Embraer aircraft Ipanema certified to fly with ethanol.

Outside FP7 but still connected with the policy goals of FP7 and future frameworks there is the participation of Embraer in the SWAFEA initiative, a tender coordinated by DG MOVE in the area of biofuels for aviation. The winning proposal was submitted by French laboratory ONERA, who already presented its final report to the European Commission on the state-of-the-art concerning the possible use of biofuels in aviation.

With the first aircraft (Fig. 2) certified in the World for the use of ethanol (the crop-duster Ipanema, [3]) and an on-going research to assess the use of biofuels in commercial aviation, Embraer was invited to participate in the SWAFEA initiative, having shared its experience with the European partners who were part of the research team lead by ONERA.

Despite no participation from Chilean and Mexican partners in FP6 and earlier calls of FP7, the dynamics above described brings an opportunity to do an assessment on factors that may contribute to consolidate such momentum and to strengthen cooperation between the EU and Latin American in aerospace R&T.

4. Barriers for a Stronger Participation of Latin American Partners in FP Programme's Projects

Beyond mapping the more dynamic organisations engaged from Latin America in aerospace R&T with EU partners, CoopAir-LA aimed to identify the barriers that, once managed, may allow such cooperation to be brought to a higher level.

Taking the opportunity associated with the organisation of three workshops under the scope of the project (held in Brazil, Argentina and Mexico), a questionnaire was delivered to the participants in order to have their views on such barriers.

As a point identified across the answers gathered from the three countries, there is the little knowledge on FP7 rules and its opportunities for funding, as well as how such funding may be compatible with the resources provided by the local Government in Latin America.

Beyond these, data from the questionnaires allowed to identify three types of barriers: Internal to the organisations; Financial; and Educational. Once addressed the associated issues, one may expect cooperation to increase between Latin American and EU organisations in the area of aerospace R&T.

Internally, most organisations who answered the questionnaires are public bodies not exclusively dedicated to the aerospace sector. This has an impact on their level of interest to invest their talent and resources in aerospace projects, both inside their home county as outside where language and distance remain barriers.

As far as the financial barriers are concerned, Latin American organisations still have some progress to make in terms of increasing their knowledge on funding mechanisms available by their home government. The same can only be truth for mechanisms made available for international cooperation in Framework Programme 7. In general, Latin American partners are not aware that, under the conditions provided by the regulation of the Framework Programme for International Cooperation, it is possible for them to get funding.

As a third type of barrier, it was possible to identify Educational issues that raise some barriers of a more structural nature. The first is related with a general lack of specific training for the aerospace sector. Despite this lower offer, the activity in the sector is low and sometimes insufficient to retain talent in the country. As a consequence, some answers in the questionnaires point to a brain drain problem with local trainees leaving to the European Union or to the United States.

Based on the creation of the Instituto Tecnológico de Aeronáutica in the late 40s, Brazil may be the less of the four countries exposed to this problem, nevertheless the high demand for qualified people by Embraer a decade ago took the company to establish a programme (the PEE) to specifically address the issue of lack of aerospace engineers in Brazil. The PEE is still active, having graduated more than 800 engineers.

5. Recommendations to Overcome the Identified Barriers

As far as the Internal barriers are concerned, Latin American organisations face similar challenges to most of their European counterparts. As an overall point in their strategy, such organisations should act on the factors that will allow them to increase their investment in R&T. At the centre of such investment, their researchers should be part of network of experts and participate in joint projects with knowledge centres. For aerospace R&T, governments in Latin America should continue to design and implement policies targeting the specific issues of the sector in their country.

On the Financial barriers, and while increasing the tools available to promote the funding available through national programmes, new initiatives may be carried out by local public bodies to raise visibility of the Framework Programme and to provide the local organisations with the relevant information on, for instance, the availability of EU funding.

Finally, on addressing the Educational barriers, data gathered from the questionnaires suggests the need for improvement on particular issues such as communication in English. Beyond these, local policies should provide incentives for the mobility of researchers, while creating or strengthening existing Post-Graduate programmes in aerospace.

Conclusions from the project suggest these to be priorities to be taken by the policymakers in Latin America which will facilitate the participation of local organisation in future projects in R&T aerospace within the EU Framework Programmes.

Flight dynamics and control	■	■	
Avionics	■	■	■
Advanced Materials		■	■
Biofuels		■	
Propulsion			■
Aerostructures	■	■	■
Noise and Vibration		■	
ATM		■	

Figure 3. Higher potential for research in CoopAir-LA's partner countries.

6. Conclusion: Towards a Stronger Participation of Latin American Organisations in R&T Projects for Space

CoopAir-LA provided a first and very important opportunity to assess the factors playing a role in the level of participation of Latin America organisations in aerospace-related R&T within the EU's Framework Programme.

Despite the identified barriers and the work that local governments and bodies should continue to do in their countries, recent years have witnessed an increasing participation of Latin American organisations in EU-funded projects related with aerospace research.

Such initiatives, mainly lead until today by Argentinean and Brazilian organisations, have provided a base for such participation to increase in the future, in fields of research clearly identified:

- Biofuels;
- Aircraft Structures: Optimized design and Manufacturing;
- Noise and Vibration;
- Flight physics: Numerical analysis and Simulation of fluid dynamics;
- Avionics.

Using the information available in the database developed as a deliverable of the project, Fig. 3 provides a chart with the distribution of such areas of expertise among CoopAir-LA's partner countries: Argentina, Mexico and Brazil.

While other area shouldn't be excluded upfront, the experience from concrete projects in the five above should be disseminated as successful cases in order to overcome some of the barriers identified in the project. Such joint effort should be coordinated among three types of players:

1. European Union bodies. The European Commission may continue its work in promoting the tools available under its Framework Programmes, particularly the funding opportunities for Latin American organisations under the provi-

sions for International Cooperation. As has been the case, EU delegations in Latin American counties should remain involved in such effort;
2. Latin American Governments. Local bodies should increase the dissemination in their countries of information concerning funding opportunities arriving from cooperation agreement with the European Union. Taking the example of Brazil, the country signed a Science & Technology Agreement with the European Commission in 2007 [4], in addition to the Strategic Partnership covering a broader range of subjects of bilateral interest [5]. Both have provided conditions for the adoption of other tools such as R&D Coordinated Calls in the fields of Energy and Information Technologies. Such path may also be considered in the future for air transport and aerospace with the three partnering countries in CoopAir-LA;
3. Research Partners. As parties with experience in participating in projects from the Framework Programme, research partners should continue their work in actively disseminating their valuable experience from participating in this type of projects, while exploring new and more ambitious opportunities to develop research work in partnership with their European counterparts.

Such opportunities can only achieve results under a win-win approach where European partners are interested and may have access to the best competencies available in their Latin American partners.

Endnotes

[1] A detailed presentation about the project was also made in Chile, although not taking place in a dedicated workshop as was the case in the three partner countries.

[2] Today, EADS CASA.

References

[1] Database of Key Actors, http://www.coopair-la.eu/home_eng.htm.
[2] http://www.rapolac.eu/participants.html.
[3] Ethanol-fueled Ipanema certified by the CTA, http://www.embraer.com/en-US/ImprensaEventos/Press-releases/noticias/Pages/IPANEMA-MOVIDO-A-ALCOOL-E-CERTIFICADO-PELO-CTA.aspx.
[4] http://ec.europa.eu/research/iscp/index.cfm?lg=en&pg=brazil-4.
[5] http://eeas.europa.eu/brazil/index_en.htm.

About the Authors

João Pedro Taborda is responsible for Government Affairs at Embraer Europe
joao.taborda@embraer.fr

Jean-Paul Domergue is Head of Operations at EADS IW – Innovative concepts & Scenarios – and in charge of R&T International Operations for Latin American countries
Jean-Paul.Domergue@eads.net

D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

Acronyms

ACARE: Advisory Council for Aviation Research in Europe
ACCENT: Adaptive Control of Manufacturing Processes for a New Generation of Jet Engine Components (EU research project)
ACO: All Condition Operations
ADS: Air Data System
AFMS: Advanced Flight Management System
AFN: Airframe Noise
AGAPE: ACARE Goals Progress Evaluation
AIAA: American Institute of Aeronautics and Astronautics
ALaSCA: Safety (and maintenance) Lattice Structures for Composite Airframes (EU research project)
ALCAS: Advanced Low Cost Aircraft Structures (EU research project)
ALICIA: All Condition Operation and Innovative Cockpit Infrastructure (EU research project)
AMS: Advanced Manufacturing Systems
ANS: Air Navigation System
ANSP: Air Navigation Service Providers
APU: Auxiliary Power Unit
ASD: AeroSpace and Defence Industries Association in Europe
ASTM: American Society for Testing and Materials
ATAG: Air Transport Action Group
ATC: Air Traffic Control
ATCO: Air Traffic Controller
ATM: Air Traffic Management
ATS: Air Transportation System
AVERT: Aerodynamic Validation of Emissions Reducing Technologies (EU research project)
AWIATOR: Aircraft Wing with Advanced Technology Operation (EU research project)
BEMOSA: Behavioural Model of Security in Airports (EU research project)
BTL: Biomass to Liquid
CAA: Civil Aviation Authority
CAEP: Committee on Aviation Environmental Protection
CALM: Computer Assisted Landing Management Systems
CAT: Clear Air Turbulence
CATS: Contract-Based Air Transport System
CDM: Collaborative Decision Making
CDTI: Centre for the Development of Industrial Technology (Spain)
CESAR: Cost-Effective Small Aircraft (EU research project)
CIMNE: Centro Internacional de Métodos Numéricos en Ingeniería (Barcelona, Spain)
CFD: Computational Fluid Dynamics
CFMU: Central Flow Management Unit
CFRP: Carbon Fibre Reinforced Plastic

CIS: Confederation of Independent States
CNRS: Centre National de la Recherche Scientifique (France)
CNS: Communication, Navigation and Surveillance
CO2: Carbone Dioxide
COTS: Customer Oriented Transport System
CREDOS: Crosswind Reduced Separations for Departure Operations (EU research project)
CRISIS: Critical Incident Management Training System Using Interactive Simulations (EU research project)
CVS: Combined Vision System
4D: Four Dimensional
DELICAT: Demonstration of LIDAR-based Clear Air Turbulence Detection (EU research project)
DES: Detached Eddy Simulation
DG MOVE: Directorate General for Mobility and Transport
DG RTD: Directorate General for Research & Innovation
DLR: Deutsches Zentrum für Luft und Raumfahrt (German Aerospace Research Centre)
DNA: Direction de la Navigation Aérienne (France)
DNW: German-Dutch Wind Tunnels
DREAM: Validation of Radical Engine Architecture Systems (EU research project)
EACP: European Aerospace Clusters Partnerships Association
EASA: European Aviation Safety Agency
EASN: European Aeronautics Science Network
EC: European Commission
ECL: Ecole Centrale de Lyon (France)
EFTA: European Free Trade Association
EIBI: European Industrial Bio-energy Initiative
ERA: European Research Area
EREA: Association of European Research Establishments in Aeronautics
ESA: European Space Agency
ESTEC: European Space Research and Technology Centre (ESA)
ETS: Emission Trading System
ETW: European Transonic Wind-tunnel
EU: European Union
FAA: Federal Aviation Administration
FFAST: Future Fast Methods for Load Calculations (EU research project)
FLPN: Flight Plan Negotiation
FMC: Flexible Matrix Composite
FMS: Flexible Manufacturing System
FOIPS: Flight Object Interoperability Proposed Standard
FP: Framework Programme
FRF: Flight Reconfiguration Function
FUTURE: Towards Flutter-Free Turbo-machinery Blades (EU research project)
FVM: Finite Volume Method
FW-H: Ffowcs-Williams & Hawkings acoustic analogy
GARTEUR: Group of Aeronautical Research and Technology in EURope
GDP: Gross Domestic Product
GFRP: Glass Fibre Reinforced Plastic

GHG: Green House Gas
GSDS: Ground Security Decision Station
GTL: Gas to Liquid
HAIC: High Altitude Ice Crystal
HEFA: Hydro-processed Ester and Fatty Acid
HIL: Human in the Loop
HISAC: High Speed Aircraft (EU research project)
HMD: Head-Mounted Display
HMS: Human Machine System
HRJ: Hydro-processed Renewable Jet
HUD: Head-Up Display
HUMAN: Model-Based Analysis of Human Errors during Aircraft Cockpit Design (EU research project)
HVO: Hydrogenated Vegetables Oils
IATA: International Air Transport Association
ICAO: International Civil Aviation Organization
ICATEE: International Committee on Aviation Training in Extended Envelopes
ICOG: Interoperability Consultancy Group
IFAR: International Forum for Aviation Research
IFR: Instrument Flight Rules
ILR: Institute for Aerospace (Institut für Luft und Raumfahrt), RWTH Aachen University
IPCC: Intergovernmental Panel on Climate Change
JAA: Joint Airworthiness Authorities
JTI: Joint Technology Initiative
KATnet: Key Aerodynamic Technologies network (EU research project)
KTH: Kungliga Tekniska Högskolan – Royal Institute of Technology (Sweden)
LCF: Low Cycle Fatigue
LDA: Latent Dirichlet Allocation
LES: Large Eddy Simulation
LIDAR: Light Detection And Ranging
MAAXIMUS: More Affordable Aircraft through Extended, Integrated and Mature Numerical Sizing (EU research project)
M-DAW: Modelling and Design of Advanced Wing Tip Devices (EU research project)
MMI: Man-Machine Interaction
MMS: Man-Machine System
MOJO: Modular Joints for Aircraft Composite Structure (EU research project)
MTM: Master in Technology Management
NACRE: New Aircraft Concept Research (EU research project)
NATO: Northern Atlantic Treaty Organization
NDT: Non-Destructive Testing
NEXTGEN: Next Generation (of Air Traffic Management systems)
NLF: Natural Laminar Flow
NLR: National Lucht – Ruimtevaartlaboratorium (National Aerospace Laboratory, NL)
NODESIM-CFD: Non-Deterministic Simulation for CFD Based Design Methodologies (EU research project)
NOx: Nitrogen Oxides
O3: Ozone
OCVM: Operational Concept Validation Methodology

OECD: Organisation for Economic Co-operation and Development
OEM: Original Equipment Manufacturer
ONERA: Office National d'Etudes et de Recherches Aérospatiales (France)
OPENAIR: Optimisation for Low Environmental Noise Impact Aircraft (EU research project)
ORINOCO: Instability Waves are one of the Recognized Mechanism for Noise Generation in High Speed Hot Jets (EU research project)
PAMELA: Process for Advanced Management of end of Life of Aircraft
PCM: Polynomial Chaos Method
PDA: Payload Driven Aircraft
PDF: Probability Density Function
PED: Pôle Européen de Développement
PIV: Particle Image Velocimetry
PLASMAERO: Useful Plasma for Aerodynamic Control (EU research project)
PLIF: Planar Laser Induced Fluorescence
PMT: Mediterranean Technology Park
PSP: Pressure Sensitive Paint
PTV: Particle Tracking Velocimetry
RADAR: RAdio Detection And Ranging
RAIN: Reducing Airframe and Installation Noise (EU research project)
RANS: Reynolds Average Navier-Stokes
REACT4C: Reducing Emissions for Aviation by Changing Trajectories for the benefit of Climate (EU research project)
RED: Renewable Energy Directive (EU)
RFS: Renewable Fuel Standard (US)
RNP: Required Navigation Performance
R&D: Research and Development
R&T: Research and Technology
RTD: Research Technology Development
RVSM: Reduced Vertical Separation Minima
SADE: Smart High Lift Devices for Next Generation Wings (EU research project)
SAFEE: Security of Aircraft in the Future European Environment (EU research project)
SATCAS: Selenia Air Traffic Control Automated Systems
SEM: Scanning Electronic Microscopy
SESAR: Single European Sky ATM Research
SFWA: Smart Fixed Wing Aircraft (Clean Sky)
SHM: Structure Health Monitoring
SID: Standard Instrument Departure
SILENCE(R): FP5 Project for Reduction of Aircraft Noise (EU research project)
SME: Small and Medium-size Enterprise
SOFIA: Safe Automatic Flight Back and Landing on Aircraft (EU research project)
SOP: Standard Operating Procedure
SRA: Strategic Research Agenda
SUPERTRAC: Supersonic Transition Control (EU research project)
SUPRA: Simulation of Upset Recovery in Aviation (EU research project)
SVELTANA: Safety (and maintenance) Improvement through Automated Flight Data Analysis (EU research project)
SVM: Support Vector Machine

SVS: Synthetic Vision System
SWAFEA: Sustainable Way for Alternative Fuels and Energy for Aviation (EU research project)
SWIM: System Wide Information Management
TANGO: Technology Applications to the Near-Term Business Goals and Objectives (EU research project)
TEAMPLAY: Tool Suite for Environmental and Economic Aviation Modelling for Policy Analysis (EU research project)
TECC-AE: Technologies Enhancement for Clean Combustion in Aero-Engines (EU research project)
TERESA: Technology Roadmap for Environmentally Sustainable Aviation
TIMECOP-AE: Towards Innovative Methods for Combustion Prediction in Aero-Engines (EU research project)
TIMPAN: Technologies to Improve Airframe Noise (EU research project)
TITAN: Turnaround Integration into Trajectory and Network (EU research project)
TRL: Technology Readiness Level
TUB: Technical University Braunschweig
TUD: Technical University Darmstadt
UAV: Unmanned Aerial Vehicle
UOP: University of Phoenix
UAS: Unmanned Aerial System
URTA: Upset Recovery Training Aid
VALIANT: Validation and Improvement of Airframe Noise Prediction Tools (EU research project)
VKI: von Karman Institute for Fluid Dynamics (Brussels, Belgium)
WBS: Work Breakdown Structure
WEZARD: Weather Hazards for Aeronautics (EU research project)
X-Noise: European Aviation Noise Research Network (EU research project)

D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

Subject Index

Innovation for Sustainable Aviation in a Global Environment
D. Knörzer and J. Szodruch (Eds.)
IOS Press, 2012

Author Index